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Manitoba
Agriculture

Papers
presented at the
32nd ANNUAL
MANITOBA SOCIETY OF SOIL SCIENCE MEETING

January 10 and 11, 1989

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These Proceedings of the Thirty-Second Annual Meeting of the Manitoba Society of Soil Science are respectfully dedicated in the honour of John (Jack) Marsden Parker who passed away January 9, 1989.

Jack Parker was Senior Stick of the Manitoba Agricultural College in 1938 and that year was awarded the University Gold Medal on graduation. He subsequently spent five years with the Royal Canadian Artillery in Canada and Europe during the Second World War. After his discharge in April of 1946, he joined the staff of the Manitoba Department of Agriculture as Soils Specialist and was the first Director of the Soils and Crops Branch, retiring in August of 1979. He was a Charter Member of the Manitoba Institute of Agrology, member of the Manitoba Horticultural Society, Honorary Life Member of the Manitoba Seed Grower's Association and the Canadian Seed Grower's Association, member of the Canadian Soil Science Society. In July, 1988 he received his 50-year pin as a member of the Agricultural Institute of Canada.

During his long and dedicated career with Manitoba Agriculture Jack was greatly admired and respected by all who worked with him and for him.

PAPERS PRESENTED

AT THE

32ND ANNUAL

MANITOBA SOCIETY
SOIL SCIENCE MEETING

HOLIDAY INN SOUTH
(Winnipeg)

January 10 and 11, 1989

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R3T 2N2

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Canada-Manitoba Soil Survey
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University of Manitoba
Winnipeg, Manitoba
R3T 2N2

Soil Management Chairperson - E. Allerdings
P.F.R.A.
100-317 Main Street South
Dauphin, Manitoba
R7N 1K8

Soil Chemistry and Fertility Chairperson - T.B. Goh
Department of Soil Science
University of Manitoba
Winnipeg, Manitoba
R3T 2N2

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SOIL CLASSIFICATION AND INTERPRETATION SECTION

The topics presented in this section focus on two main areas of interest. The first series of six papers, provides a review and update on the nature of the soil resource data base for Manitoba. The first three topics include a report on soil survey coverage for the province,a description of an improved computerized method of storing, analyzing and presenting soil data, and a description of the recently published Generalized Soil Landscapes Map (GSLM) of Manitoba.

The next three papers deal with reliability, application and use of soil resource information. These papers discuss the utility of soil data which can be obtained from maps, legends and reports, as a function of user requirements. The first paper assesses the reliability of map delineations and the agronomic data derived therefrom. The following paper discusses the application of this data through the use of a simulation model to determine the probability of wheat yields on Manitoba soils as portrayed on the Generalized Soil Landscapes Map (GSLM). The third paper describes the procedure utilized to characterize and classify the surface pH of soil landscapes shown on the GSLM for Agro Manitoba.

The last four presentations in the section focus on pedological research and soil characterization studies of North Dakota soils. The origin of argillic horizons in calcareous till is discussed and soil characteristics of typical wetlands and salt affected areas are presented.

THE CHANGING NATURE OF THE SOIL RESOURCE DATA BASE FOR MANITOBA

R.E. Smith and W.R. Fraser
Canada-Manitoba Soil Survey

ABSTRACT

A major effort is underway to convert Manitoba soil maps at various scales (from 1:1 million to 1:20,000) from older hard copy and CanSIS digitized versions to more modern digital geographical information system formats. In Manitoba, this conversion is developing along two parallel, compatible tracks:

a) The Soil Information Management System (SIMS) - a generalized soil data base that provides information on a quarter section basis. This generalized data base provides information on 305,000 quarter sections in Agro-Manitoba;

b) The CanSIS-ARC/INFO GIS - This data base involves the conversion of existing soil maps (all scales) to digital format (ARC files) and the development of extensive soil attribute data bases (INFO files).

The enhancement of available map coverage, in particular, the "Soil Association" reconnaissance maps, is required before successful conversion to CanSIS ARC/INFO is accomplished.

Conversion of soil maps and data bases to electronic format will have implications for future soil report design and update procedures. The data bases, rather than the printed soil and interpretive maps, will be our main product. Updates to the bases will be made continuously with hard copy output products representing "snapshots" of the data base made at regular intervals.

INTRODUCTION

Currently, a major nation-wide effort, coordinated by the Land Resource Research Centre (LRRC) in Ottawa, is underway to convert soil resource maps from the present cartographic system following a critical review in 1986. This cartographic system, operational since 1974, is severely limited in its analytical capabilities, is difficult to support and is relatively expensive to operate. In addition, it does not have capabilities to communicate easily with other systems nor possess other modern GIS capabilities so necessary for land evaluation.

The current system employs out-of-date hardware and custom software and is very difficult to maintain. However, it has served the uses for which it was developed and has accommodated some of the modern GIS capabilities. Unfortunately, it is unable to overlay other data, has not incorporated geographic referencing, an ability to window or merge maps nor communicate by remote access.

The objective of this major project is to provide a) in Canada, a distributed geographic information system (including data files and computer data processing capabilities) encompassing a coordinated network of computers for inputting, managing and interpreting tabular and cartographic soil resource data for Soil Survey and a variety of land evaluation, land management and use applications; b) to convert all existing soil resource information to utilize modern ARC/INFO GIS capabilities.

THE NATURE OF DATA CONVERSION AND HARDWARE/SOFTWARE

Enhancement in Manitoba

In Manitoba, the conversion of all existing soil resource information in the present CanSIS format, as well as data not yet in the system, is being developed along two parallel, compatible tracks:

a) The Soils Information Management System (SIMS) - a computer database system that provides access to two major soil resource data bases; a quarter-section (cellular) database identifying all major and minor soil landscape attributes for 305,000 quarter sections in Agro-Manitoba and, secondly, all soil survey site inspection data collected since 1977. SIMS also provides a means to link other data bases such as Manitoba Crop Insurance Corporation productivity indices and risk zones; provincial soil test data, latitude and longitude coordinates through CROPP and other information stored in a similar quarter section digital format.

SIMS is presently maintained on University of Manitoba mainframe computers and is accessible to all account holders. It is user friendly, menu based and designed for direct use by soil surveyors, land resource specialists, economists and other researchers in land resource assessment work. Numerous output and display options are provided including the ability to extract portions of the database and to download the information to personal computers for further analysis.

A more complete description of SIMS can be found in the paper by W.R. Fraser, "A Soil Resource Geographic System for Manitoba", in Proc. 32nd Annual Manitoba Soil Sci. Soc. Meeting, Jan. 10-11, 1989.

b) The CanSIS-ARC/INFO Geographical Information System - a polygonal, vector based, data base management system employing ARC/INFO software and an improved, more efficient and less costly network of micro, mini and mainframe computers for inputting, managing and interpreting tabular and map data.

A major national coordination role is headed by B. MacDonald of the Information System and Cartographic Unit of LRRC. This central agency provides the major capability to store, manage, analyze and output soil survey data in Canada. At present, a number of VAX 11/785 mini computers are dedicated to the national operation of CanSIS. Capability to remotely access this central agency capability is presently being enhanced by a network of micro computer based data management systems.

The aim of the Canada-Manitoba Survey is to create an independent, micro-computer driven, remote (from Ottawa) work station by the Spring of 1989. An IBM Compaq 386 PC with appropriate software (TYDAC, TERRASOFT or PAMAP) will allow communication with both Ottawa and other similar systems operating in the province; the digitizing of most maps generated by the Soil Survey; permit analysis and output of map and tabular data for purposes of soil survey, land evaluation and other applications.

The ARC/INFO System Components

The ARC/INFO software purchased by LRRC represents a sophisticated computer mapping and geographic information management system. The system has two components:

- ARC software handles the actual cartographic data files which contain the digitized point, line, and polygon information. It permits map sheet manipulation options - windowing, merging, contiguity analysis, map overlaying capability, allow remote access and can communicate with other GIS, to name some.

- INFO software is a fully relational Data Base Management System (DBMS) which stores and manipulates map polygon attribute data. The focus of these files is to provide, more effectively, the data required to assess land productivity for a variety of agricultural uses, in particular, the ability of soils to supply water and nutrients to plants, establish indices of erosion risk and so on.

CanSIS-INFO File Structure

The INFO file structure is illustrated in Figure 1. Five INFO files are proposed:

- The Project File (not shown) - documents the nature of each soil survey project in terms of methods, classification employed, objectives to be served, etc.

- The Polygon File - provides a link between map polygons, identified by numbers, in ARC, and corresponding Map Unit Symbols.

- The Soil Map Unit File (SMUF) - links Soil Map Units to Soil Names and landscape modifiers. It also serves to document map unit concepts for correlation purposes for each map in ARC.

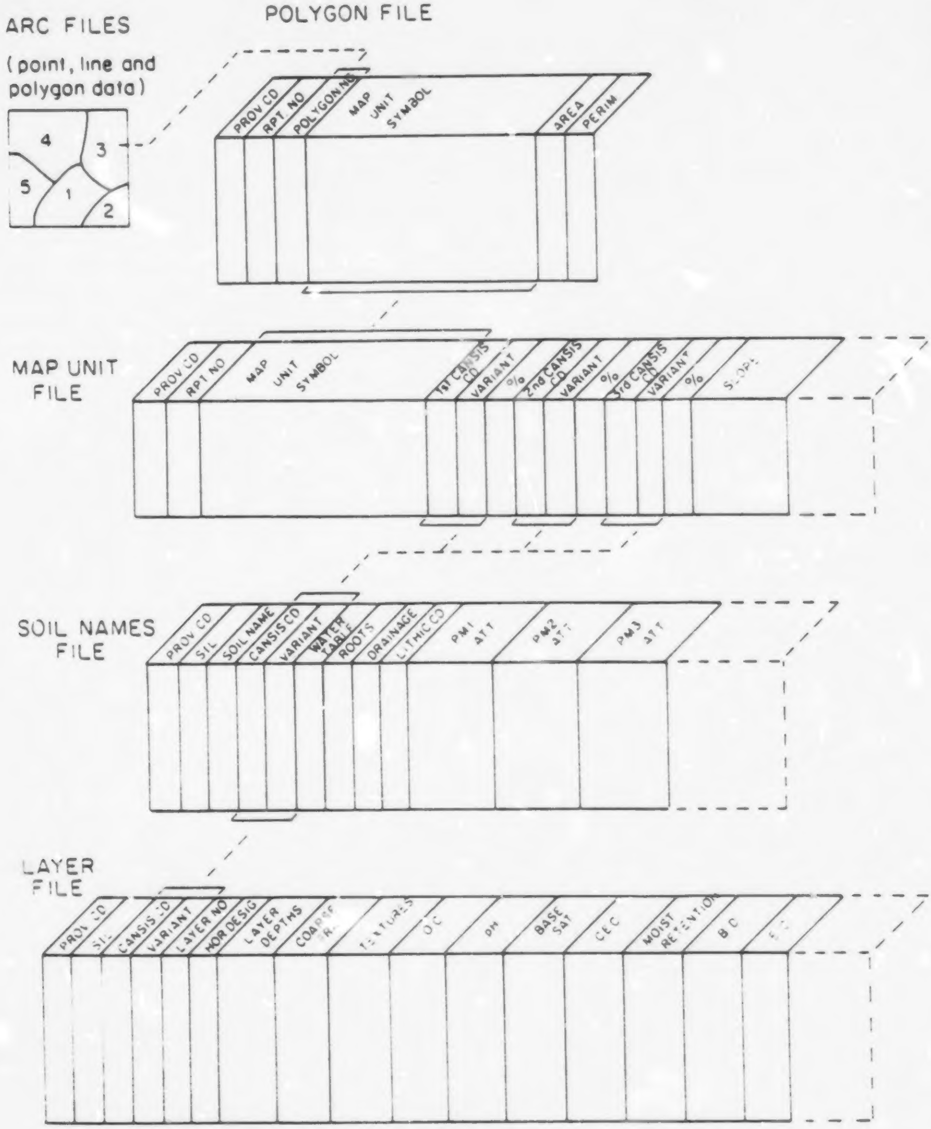
- The Soil Names File (SNF) - links soil names to attributes and to attributes that pertain to the whole soil such as classification, drainage and general parent material attributes. Approximately 1,900 Soil Series and Phases have been identified in mapping the soils of Manitoba. This global file of 35 data fields is 90 percent complete for soil maps that have been digitized. The SIMS-DBMS is able to access this file.

- The Soil Layer File (SLF) - a global file that links soil names to attributes that vary by horizon or layer in a vertical direction. This file contains 53 data fields and is approximately 50-60 percent complete for digitized maps in ARC. The SIMS-DBMS is able to access these data as well.

A more complete description of ARC/INFO is contained in "Manitoba CanSIS Update" by W.R. Fraser in 30th Annual Man. Soil Sci. Soc. Meetings Proc., Jan. 6-7, 1987.

FIGURE 1

MANDATORY CANSIS ARC/INFO FILE STRUCTURE (PROVISIONAL)


ARC FILES
(point, line and polygon data)
4
3
5
1
2
POLYGON FILE
PROV CD
RPT NO
POLYGON NO
MAP UNIT SYMBOL
AREA
PERIM
MAP UNIT FILE
PROV CD
RPT NO
MAP UNIT SYMBOL
1st CANSIS CD
VARIANT
%
2nd CANSIS CD
VARIANT
%
3rd CANSIS CD
VARIANT
%
SLOPE
SOIL NAMES FILE
PROV CD
SIL
SOIL NAME
CANSIS CD
VARIANT
WATER TABLE
ROOTS
DRAINAGE
LITHIC CD
PM1 ATT
PM2 ATT
PM3 ATT
LAYER FILE
PROV CD
SIL
CANSIS CD
VARIANT
LAYER NO
HOR DESIG
LAYER DEPTHS
COARSE FRAG
TEXTURES
OC
pH
BASE SAT
CEC
MOIST RETENTION
BD

Implementation of CanSIS

In order to utilize ARC/INFO data analysis capability, it is necessary to organize and standardize all existing map and soil attribute data to classification, field and laboratory methods currently employed by Canada-Manitoba Soil Survey. Present soil map coverage for Manitoba has very considerable variation both in terms of survey intensity level (SIL) or scale and in changes to the methods and classification standards employed since surveys were initiated some 50 to 55 years ago. In addition, substantial overlap of detailed and semi-detailed coverage for 30 percent of Agro-Manitoba has created considerable difficulty in communicating the best possible available resource data to users. The current major effort underway by Canada-Manitoba Survey initiated in 1986, is an attempt to rationalize these problems through the implementation of ARC/INFO.

The Nature of Soil Map Coverage Through ARC/INFO

In Manitoba, soil map coverage exists at 3 major levels of survey intensity or scale:

1. The Generalized Soil Landscape Map (GSLM) - This single map provides generalized information over the entire province at a scale of 1:1M. This map is presently in ARC. Supporting information files through an extended legend will be available for such province-wide and regional applications, including the development of revised MCIC Risk Areas by 1988-89 fiscal year end.

2. The Reconnaissance Soil Survey at 1:125K - 1:100K Scale - The conversion to ARC/INFO electronic format of reconnaissance level is of utmost importance since these data represent the most extensive, single scale uniform soil data base for the province - all of Agro-Manitoba and about 75 percent of the commercial forest area. The conversion of these data bases, presently underway by the federal survey unit, will involve some field inspection to verify map and legend data, sampling soils not adequately characterized, the use of air photos to improve landscape attribute data and the integration of other related hydrological and terrain data relevant to soil characterization. Three groups of maps requiring varying input for conversion are recognized:

   a) The "Soil Association" Based Reconnaissance Maps - By far the most important group of maps are the 7 "Soil Association" maps covering 6.7 million hectares in southern Manitoba. This group of maps represents the sole source of soils data for approximately 65 percent of Agro-Manitoba not presently covered by more detailed resurveys. Before these maps can be input into ARC, a major translation of existing polygon data, i.e. Association names and overprinted phase symbols, must be interpreted, correlated and field verified before appropriate INFO files can be constructed. See Figure 2.

   b) The "Soil Series" Based Reconnaissance Maps - These more recent map projects (15 projects covering 13.5 million hectares) are deemed to possess adequate map information for most survey information applications. However, translation of existing map symbols to 3-letter "Soil Series" codes and

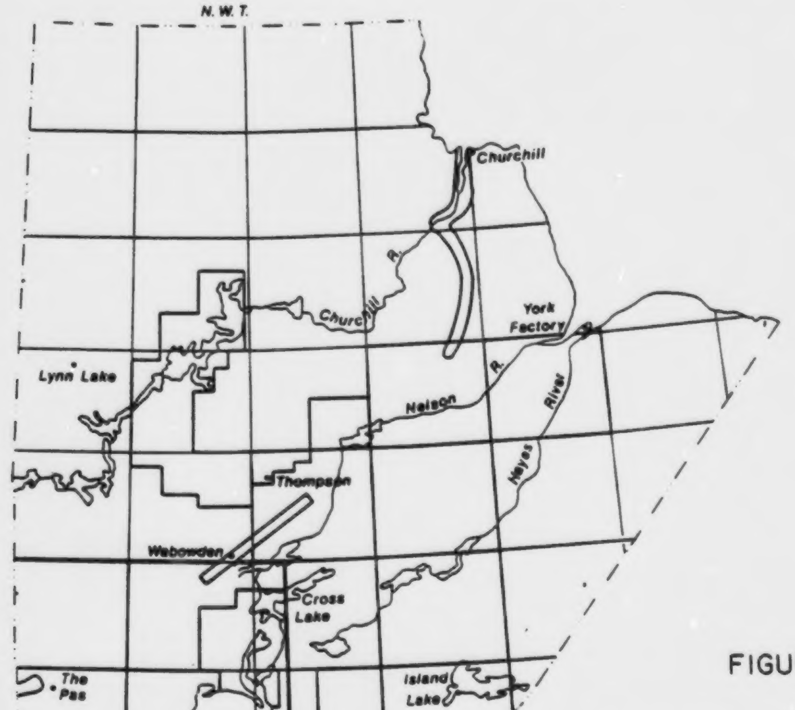

N.W.T.
Churchill
Churchill R.
York Factory
Lynn Lake
Nelson R.
Hayes River
Thompson
Wabowden
Cross Lake
The Pas
Island Lake
Lake Winnipeg
Berens R.
SASKATCHEWAN
ONTARIO
Dauphin
Assiniboine
Brandon
River
Winnipeg
Red R.
U.S.A.

FIGURE 2

ARC/INFO STATUS

Reconnaissance 1:125K
"Soil Association" Map
7 Projects, 6.7 Million Ha.

▨ Published Maps, Adjustments And Correlation Required

Sole Source Of Data For 65 % Agro-Man.

▩ In Production

translation of differing legends to a common extended legend is still required. Little or no field verification, a minimum of soil sampling to improve physical attribute data, are identified as tasks needed to improve these data to ARC/INFO standards. Six projects have been converted to ARC; three others are scheduled to be converted shortly, and six remaining projects are in various stages of map production. The Pointe du Bois, Swan Lake and Duck Mountain projects are most advanced and likely to be in ARC sometime in 1989-91. See Figure 3.

c) The Biophysical Land Classification Maps - This set of 11 maps covering approximately 12.5 million hectares provide the sole source of soils data for an important portion of Manitoba's forest land and hydro-electric transportation corridor. These maps and accompanying data require a substantial effort to convert them to ARC/INFO standard and are presently not scheduled for conversion. See Figure 4.

3. The Detailed Resurvey Maps at 1:20K to 1:50K Scale - Approximately 80 projects comprised of 363 maps provide enhanced soil data for about 35 percent of the cultivated acreage in southern Manitoba. About 218 of these have already been converted into ARC and accompanying INFO files are scheduled to be completed in 1989-90. Current projects underway in the province will be prepared according to required standards. See Figure 5.

Conversion Costs

It is estimated that it will take approximately 6 PY's and approximately $750K over 3 years in additional resources to Soil Survey to complete scheduled conversion to ARC/INFO. This does not include the Biophysical maps.

Future Maps and Reports

The conversion of soil maps and data bases to electronic formats will have implications for future soil map and report design and data base enhancement procedures. The data bases, both SIMS and ARC/INFO, will be the main products of the joint Soil Survey program. Updates to these data bases will be made at scheduled regular intervals with hard copy output products such as generic soil maps (as at present) representing "snapshots" of the data base at given points in time.

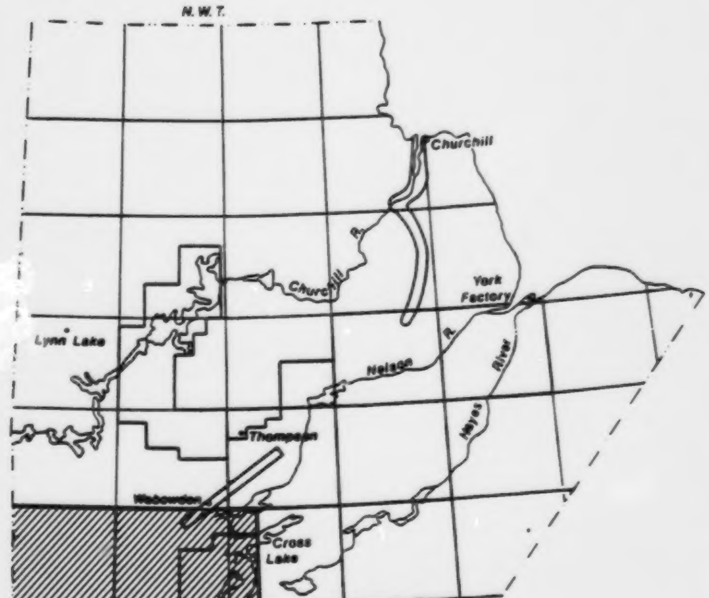

N.W.T.
Churchill
Churchill R.
York Factory
Lynn Lake
Nelson R.
Hayes River
Thompson
Wabowden
Cross Lake
Island Lake
The Pas
Lake Winnipeg
Berens R.
Dauphin
Assiniboine
Brandon
River
Winnipeg
Red R.
SASKATCHEWAN
ONTARIO
U.S.A

FIGURE 3

ARC/INFO STATUS

Reconnaissance 1:125K - 1:100K
15 Projects, 13.5 Million Ha.

▩ In Arc, Info Files To Be Prepared.

░ Scheduled For Conversion To Arc

▨ In Production

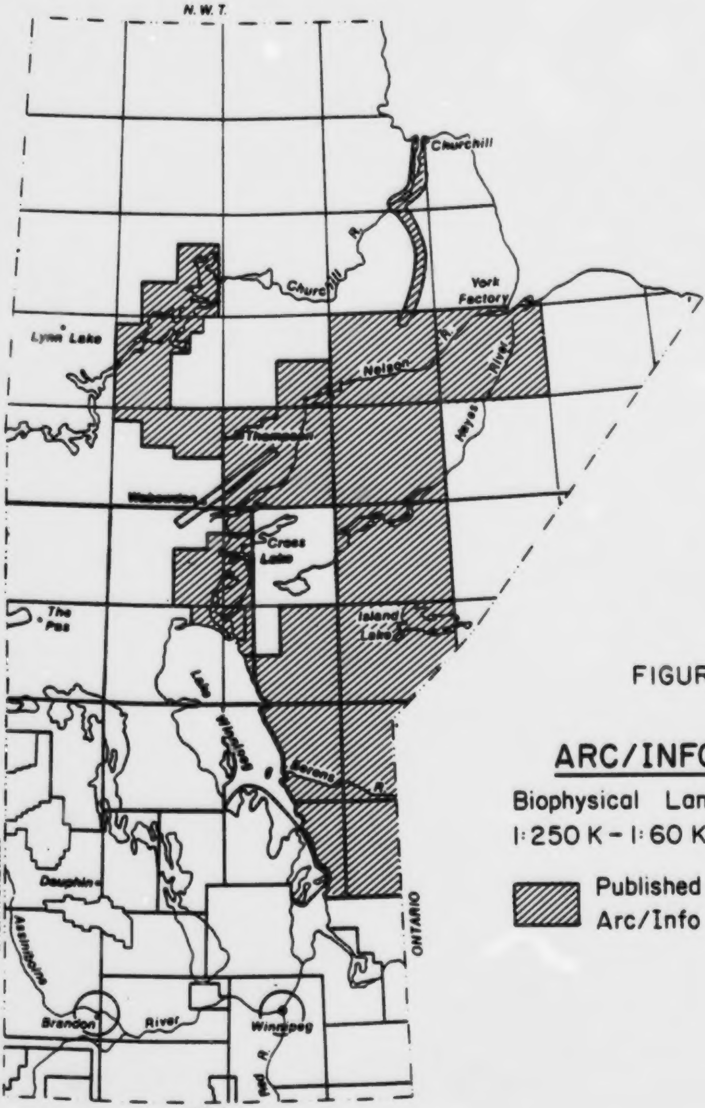

N.W.T.
Churchill
Churchill R.
York Factory
Lynn Lake
Nelson R.
Hayes River
Thompson
Wabowden
Cross Lake
The Pas
Island Lake
Lake Winnipeg
Berens R.
Dauphin
Assiniboine
Brandon
River
Winnipeg
Red R.
SASKATCHEWAN
ONTARIO
U.S.A.

FIGURE 4

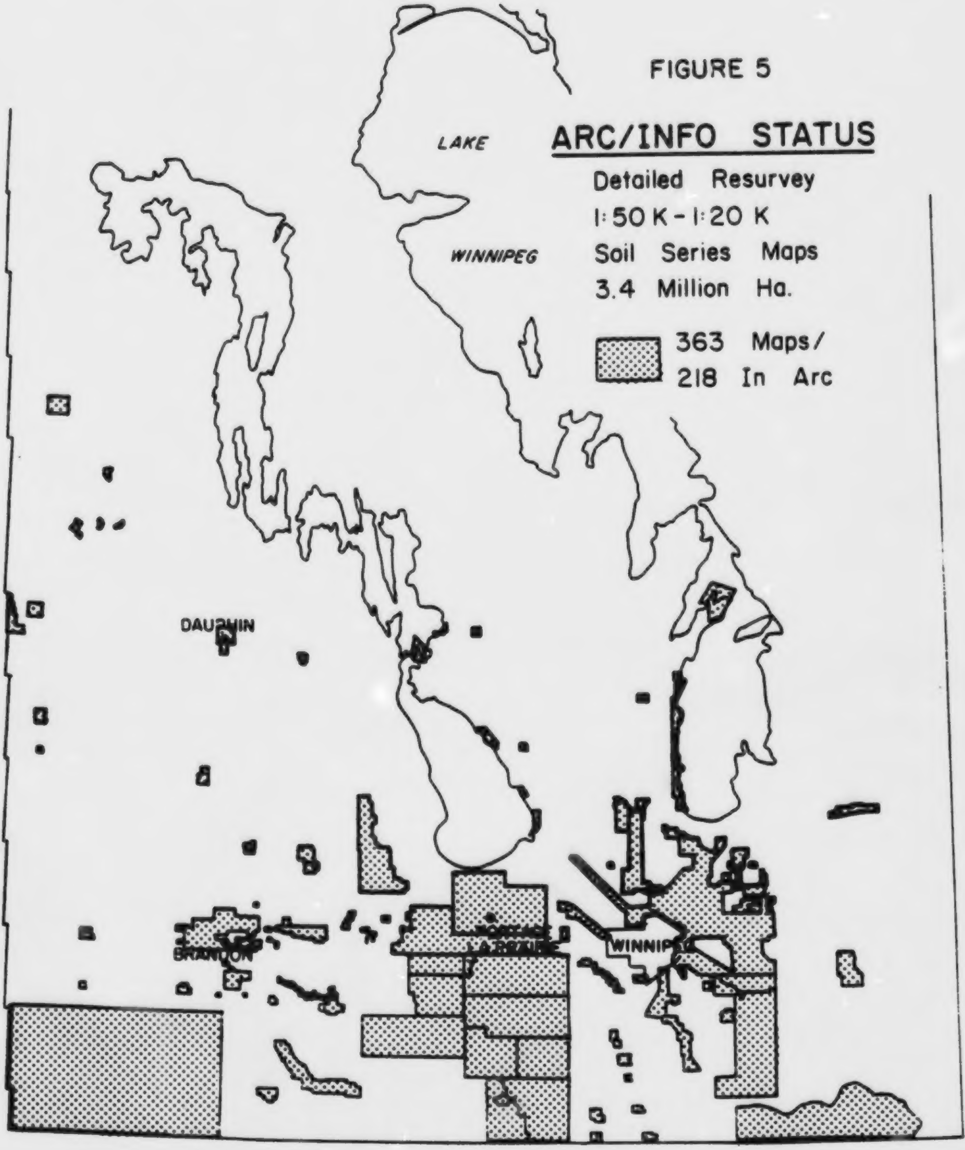
ARC/INFO STATUS

Biophysical Land Classification
1:250 K – 1:60 K

▨ Published Maps. Input To Arc/Info Not Scheduled

FIGURE 5

ARC/INFO STATUS


Detailed Resurvey
1:50 K - 1:20 K
Soil Series Maps
3.4 Million Ha.
▨ 363 Maps/
218 In Arc
LAKE
WINNIPEG
DAUPHIN
BRANDON
PORTAGE LA PRAIRIE
WINNIPEG

SOIL INFORMATION MANAGEMENT SYSTEM FOR MANITOBA

W.R. Fraser
Canada-Manitoba Soil Survey

Canada-Manitoba Soil Survey information has traditionally been delivered as a series of paper maps and reports covering specific portions of Manitoba. The conversion of soils information to various computerized formats was initiated in 1972 with the establishment of the Canadian Soil Information System (CanSIS). The use of various discrete data files to store soils information was previously described by Fraser and Mills (1982).

The recent advent of computerized geographic information systems (GIS) has revolutionized the manner in which geographic information (i.e. soils) can be accessed and portrayed. These systems rely on the integration of comprehensive database information with map information. Two types of GIS have emerged: polygonal and cellular.

MANITOBA SOIL SURVEY POLYGONAL GIS ACTIVITIES

The main commitment of Canada-Manitoba Soil Survey EDP resources since 1986 has been towards the conversion of all existing map coverages into ARC/INFO, a commercial polygonal GIS. A major effort is underway in all regional soil survey units in Canada to provide soil map and database information in the new CanSIS-ARC/INFO database format adopted by the Land Resource Research Centre (LRRC) of Agriculture Canada. Details of this program are described in a paper presented at the 30th Annual Manitoba Soil Science Meeting (W. Fraser, 1987). Current and future Manitoba Soil Survey GIS database coverages are reviewed in a separate paper (R.E. Smith, 1989).

Sophisticated, polygonal GIS are used to portray all of the intricate soil polygon boundary information inherent in individual soil maps. A major investment in hardware, software and staff training is required to handle such GIS operations. Overlays of additional polygonal database coverages require complex computer operations as a new combined set of polygons is created and minor "sliver" polygons must be eliminated. Agencies such as the Manitoba Forestry Branch, Parks Canada, and the Provincial Surveys and Mapping Branch will soon have the capability of exchanging and integrating polygonal GIS data in the near future.

MANITOBA SOIL SURVEY CELLULAR GIS ACTIVITIES

Basic soil resource information is essential for agencies with responsibility for monitoring or recommending land management practices and for national resource policy decision making and program delivery.

It has long been recognized that many of these agricultural agencies routinely collect, manage and interpret computerized land information on a Dominion Land Survey (DLS) basis. That is, database records are created and accessed based on Township-Range-Section and quarter section designations. These are essentially cellular geographic information systems, with the cells corresponding to individual DLS sections or quarter sections of land. The overlay and manipulation of datasets in a cellular GIS is comparatively simple, requiring only the matching of records with common quarter section data fields.

Many useful comparisons are feasible once basic soil survey information is available in this format. For example, the Provincial Soil Testing Lab and the Manitoba Crop Insurance Corporation collect information on nutrient status and crop yields on a quarter section basis. Correlation of such data with specific recognized soil types could be readily achieved that would be of practical benefit to all contributing agencies. Similar comparisons could be achieved between soil types and various economic or land use databases when all are available on a common quarter section based format.

Soil Survey information has traditionally been portrayed as a variety of polygonal map coverages with various scales and soil legend formats. Few agencies have had the resources or expertise to convert large amounts of soils information to a uniform quarter section cellular format for their own needs.

A large volume of soil site data has also been routinely collected, keypunched, and archived by the Manitoba Soil Survey as part of the routine field inventory activities to produce soil maps. This point source data has not traditionally been accessible to client groups, many of which conduct their own field investigations of soil conditions in selected areas. Providing soil survey site information in convenient, accessible formats upon demand would aid in any decision making processes and avoid expensive redundancies in soil sampling and analysis by various agencies.

The Canada-Manitoba Soil Survey Unit lacks sufficient in-house resources to develop cellular GIS and site databases for delivering soil resource information. A joint Manitoba Soil Survey-University of Manitoba Soil Science Dept. proposal was submitted and approved as a research project under the Canada-Manitoba Economic and Regional Development Agreement (ERDA). The resulting Agri-Food Project (23104-1), entitled Development of a Soil Survey Information Management System for Manitoba, was designed to achieve these basic objectives. A University programmer/analyst and a data compiler were hired to design and develop the database system, with overall project management and technical and scientific advice provided by the Canada-Manitoba Soil Survey staff. The contract period for the design and development of an operational Soil Information Management System ("SIMS") was from September, 1987 to Oct. 31, 1988. An additional Agri-Food Project has been initiated to develop additional features for the system.

The results reported in this paper are those features of the system that are currently operational (January, 1989) and accessible to all client groups.

SIMS Design Considerations

Several key design criteria influenced the final design of the Soil Information Management System (SIMS). These included the relevant data sources that could be acquired and the contract requirements to utilize the University of Manitoba mainframe computer system. No mainframe relational database management system was available, and existing hierarchical systems did not meet cost or ease of use criteria. A custom developed menu driven system was developed using TSO CLIST procedures.

Additional SIMS design considerations were as follows:

1. A consistent quarter section cellular database coverage should be developed for all of Agro-Manitoba. Additional land resource data from PSTL and MCIC were also investigated for inclusion under SIMS.

2. The system must be "user friendly". Direct access is required from any location for pedologists or resource specialists with limited computer skills.

3. Flexible data extraction and output formats were required.

4. Data should be downloadable to clients' personal computers for further analysis. SIMS should assist users in downloading and organizing soils data using dBase software.

5. SIMS should function with minimal additional PY and financial requirements from soil survey staff. This led to several additional design criteria:

   i) No programmer intervention for normal operation,
   ii) "User pay" access policy for clients (automatic),
   iii) "Read only" access to maintain database integrity,
   iv) Integrate with current operational soil survey database formats whenever feasible to eliminate redundant maintenance (i.e. Daily file, Soil Names file and Soil Layer file),
   v) Efficient archive and update procedures required for all active databases,
   vi) All system operation costs should be minimized.

SIMS Database Contents and Operation

The Soil Information Management System (SIMS) is a computer database system designed to provide access to soil resource databases. Figure 1 provides a schematic diagram of the overall database structure.

Direct access to SIMS is available to all computer account holders on the University of Manitoba mainframe computer system via a terminal or personal computer with a modem and telecommunications software. Users outside of Winnipeg may use their nearest DATAPAC node to access the University system. Once logged on to the University mainframe, access to SIMS is via a standard command ("%SOILS"). The SIMS Main Menu is then displayed, listing available database options. Two major databases are currently operational: the Generalized Soil ("1/4 Section") database and the Soil Survey site inspection database. Once a database option is selected, further submenus appear to prompt the user for the particular area of interest, the data required, and the output format desired.

SIMS Generalized Soil ("1/4 Section") Database

This database contains information for approximately 305,000

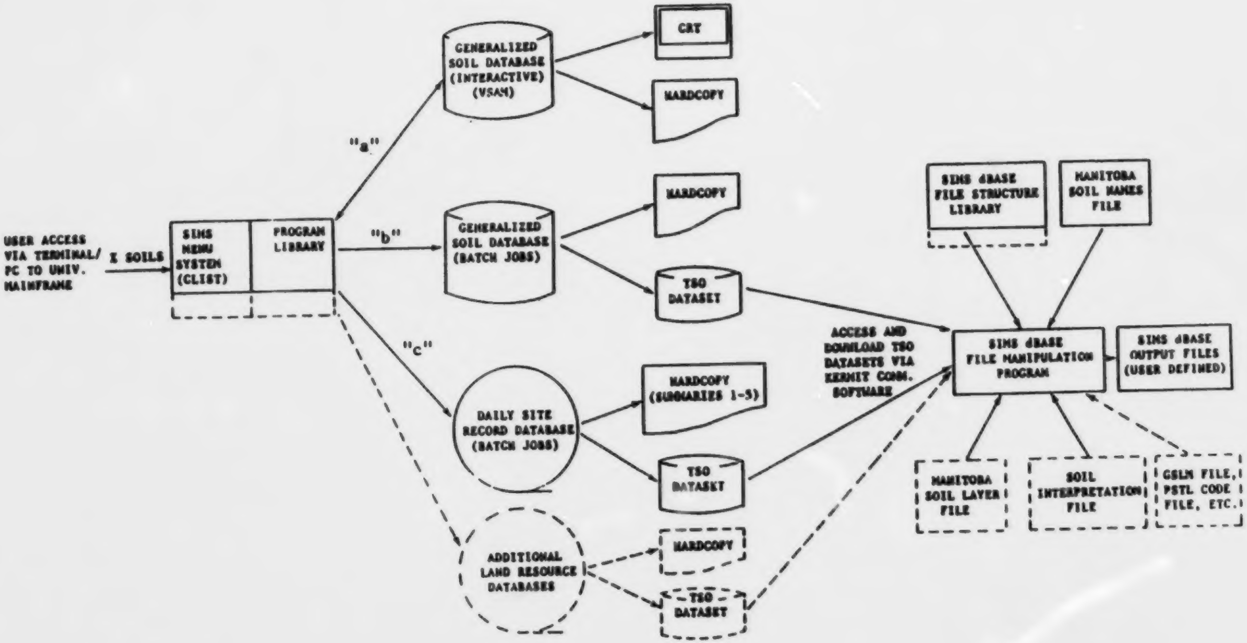

USER ACCESS VIA TERMINAL/ PC TO UNIV. MAINFRAME
X SOILS
SIMS MENU SYSTEM (CLIST)
PROGRAM LIBRARY
"a"
"b"
"c"
GENERALIZED SOIL DATABASE (INTERACTIVE) (VSAM)
CRT
HARDCOPY
GENERALIZED SOIL DATABASE (BATCH JOBS)
HARDCOPY
TSO DATASET
DAILY SITE RECORD DATABASE (BATCH JOBS)
HARDCOPY (SUMMARIES 1-5)
TSO DATASET
ADDITIONAL LAND RESOURCE DATABASES
HARDCOPY
TSO DATASET
ACCESS AND DOWNLOAD TSO DATASETS VIA KERMIT COMM. SOFTWARE
SIMS dBASE FILE STRUCTURE LIBRARY
MANITOBA SOIL NAMES FILE
SIMS dBASE FILE MANIPULATION PROGRAM
SIMS dBASE OUTPUT FILES (USER DEFINED)
MANITOBA SOIL LAYER FILE
SOIL INTERPRETATION FILE
GSLM FILE, PSTL CODE FILE, ETC.

Figure 1. Schematic diagram of Soil Information Management System (SIMS) database structures and operation.

quarter sections (76,000 square miles or sections), covering virtually all of Agro-Manitoba.

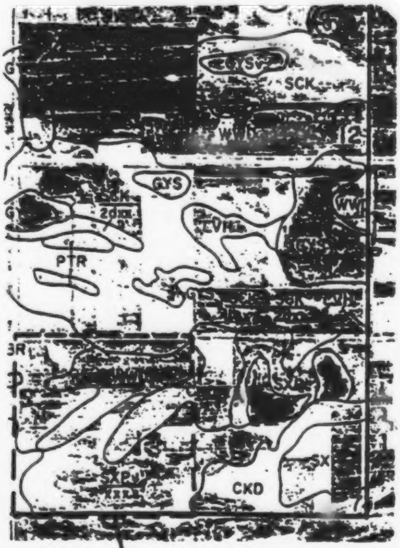
The SIMS menu system allows selection of GSDB data records by DLS coordinates for all Ranges in southern Manitoba (0 to 17E and 0 to 29W) and all Townships up to 55 (just south of The Pas, Manitoba). Any gaps in particular data source coverages show up as blank values in the corresponding data fields on output requests.

The Generalized Soil Database has been compiled from six separate sources, all of which have partially overlapping coverages. These data sources and their coverages are as follows:

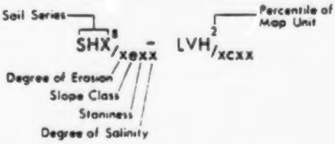
Data Source	**Coverage (sections)**
Canada-Manitoba Soil Survey Major/Minor/Minor soil series code phase information (erosion, topography, stoniness, and salinity)	11,104 sections Mainly areas with newer detailed soil map coverage
Canada-Manitoba Soil Survey Generalized Soil Landscape Map Polygon number (1:1 million scale map)	57,587 sections
Provincial Soil Testing Lab Major/Minor soil codes derived from Soil Survey reconnaissance soil maps	69,552 sections
Manitoba Crop Insurance Corporation Risk Zone and Productivity Index	39,483 sections
Manitoba Crop Insurance Corporation Municipality codes	39,483 sections
Canadian Wheat Board Conformal Representation of the Prairie Provinces (CROPP) database; latitude and longitude coordinates for the centroid of each section and quarter section (decimal degrees)	54,855 sections

An example of typical coding of Major/Minor/Minor soil code and phase information from detailed soil maps is shown in Figure 2. Note that the original soil map contains the most detailed representation of soil variability for any particular area. The SIMS format, while generalized, provides soils data in a single consistent database that is easily accessible and compatible with other databases utilizing a DLS format.

SIMS provides two different access methods to the Generalized Soil Database to handle separate types of requests. A VSAM file version ("SIMS Main Menu, Option A") provides interactive access to the data. This is for smaller, immediate requests that are specified according to Dominion Land Survey (DLS) coordinates of Township, Range and Section number. Output is limited to screen displays or hardcopy printouts. An example of a typical interactive output for a particular section of land is shown in Figure 3.


SCK
GYS
WWD
SCK
2dxx
GYS
LVH
WWD
PTR
SXP
CKD
SX
12

SEE	Sewell	Fine sandy loam	Poor	Rego Humic Gleysol
SHX	Shilox	Loamy fine sand	Well	Orthic Regosol
SCK	Stockton	Loamy fine sand	Well	Orthic Black
SXP	Sutton	Clay loam	Poor	Rego Humic Gleysol
WWD	Wellwood	Clay loam	Well	Orthic Black


Soil Series
Percentile of Map Unit
SHX 8 /xexx - LVH 2 /xcxx
Degree of Erosion
Slope Class
Stoniness
Degree of Salinity

Degree of Erosion

x	non-eroded or minimal
1	slightly eroded
2	moderately eroded
3	severely eroded
o	overblown

Slope Class

x	0-2%	level to very gently sloping
c	2-5%	gently sloping
d	5-9%	moderately sloping
e	9-15%	strongly sloping
f	15-30%	steeply sloping
g	30-60%	very steeply sloping
h	over 60%	extremely sloping

Stoniness

x	non-stony
1	slightly stony
2	moderately stony
3	very stony
4	exceedingly stony
5	excessively stony

Degree of Salinity

x	non-saline
s	weakly saline
t	moderately saline
u	strongly saline

RECORD KEY	1/4 SECT.	SOIL AND PHASE CODES					
		MAJOR		MINOR		MINOR	
00713007	NW	SCK	lcxx	SCK	2dxx	GYS	xxxx
"	NE	GYS v	xxxx	SCK	lcxx	SCK	2dxx
"	SW	SXP v	xxxs	CBR	xxxx	WWD	xxxx
"	SE	CKD	xxxx	SXP	xxxx	SXP v	xxxs

Figure 2. Example of SIMS Generalized (1/4 Section) Soil Database coding from detailed soil survey maps.

```
NW Qtr of Sec 01  Tp 34  Rg 29  W
*********************************
Detailed Map Soil Series and Phase Codes
Major  (dominant)               =  MNS           XX1X
Minor1 (subdominant)            =  TBN           XB1X
Minor2 (second subdominant)     =  NOV           XXXX
Report number                   =  D066
Municipality code               =  871
MCIC code/risk zone             =  C/08
GSLM Polygon #                  =  186
Recon.soilcode (PSTL maj/min)   =  4518 6303
CROPP coordinates (sect/qtr)    =  0518874 1014471   / 0518910 1014530
UTM Coordinates   (sect/qtr)    =                    /

NE Qtr of Sec 01  Tp 34  Rg 29  W
*********************************
Detailed Map Soil Series and Phase Codes
Major  (dominant)               =  TBN           XB1X
Minor1 (subdominant)            =  NOV           XXXX
Minor2 (second subdominant)     =  MNS           XB1X
Report number                   =  D066
Municipality code               =  871
MCIC code/risk zone             =  C/08
GSLM Polygon #                  =  186
Recon.soilcode (PSTL maj/min)   =  4518 4518
CROPP coordinates (sect/qtr)    =  0518874 1014471   / 0518910 1014412
UTM Coordinates   (sect/qtr)    =                    /

SW Qtr of Sec 01  Tp 34  Rg 29  W
*********************************
Detailed Map Soil Series and Phase Codes
Major  (dominant)               =  TBN           XB1X
Minor1 (subdominant)            =  PMU           XXXX
Report number                   =  D066
Municipality code               =  871
MCIC code/risk zone             =  C/08
GSLM Polygon #                  =  186
Recon.soilcode (PSTL maj/min)   =  4518 4518
CROPP coordinates (sect/qtr)    =  0518874 1014471   / 0518838 1014530
UTM Coordinates   (sect/qtr)    =                    /

SE Qtr of Sec 01  Tp 34  Rg 29  W
*********************************
Detailed Map Soil Series and Phase Codes
Major  (dominant)               =  MNS           XB1X
Minor1 (subdominant)            =  TBN           XB1X
Minor2 (second subdominant)     =  NOV           XXXX
Report number                   =  D066
Municipality code               =  871
MCIC code/risk zone             =  C/08
GSLM Polygon #                  =  186
Recon.soilcode (PSTL maj/min)   =  4518 4518
CROPP coordinates (sect/qtr)    =  0518874 1014471   / 0518838 1014412
UTM Coordinates   (sect/qtr)    =                    /
```

Figure 3. Typical printout of soil information for a section of land using SIMS Generalized Soil database (Option A).

The second version of the Generalized Soil Database ("SIMS Main Menu, Option B") allows access to data by secondary data field keys. With this version, users have the option of accessing data records by either DLS coordinates, municipality code, soil report number, or by GSLM polygon numbers. Output can be user specified as either hardcopy printouts, or computer datasets. These datasets can be copied to other mainframe files or later downloaded to a microcomputer for further analysis. Since these requests are done in batch mode, output is available following job completion. This time can vary from a few minutes to a few hours, depending on system activity and job priority.

SIMS Soil Survey Site Inspection Database

The Soil Survey Site Inspection Database is also accessible via SIMS ("Main Menu, Option C"). This consists of routine field inspection ("Daily Form") data collected by the Manitoba Soil Survey. Since 1977, over 50,000 site inspection records have been added to this database; approximately 5,000 continue to be added each year. To access this data, the user can specify the area of interest in either DLS coordinates or by Soil Survey Project Code. An on-line Help listing of acceptable project names and codes is available. Output choices include a set of site data summaries sorted by unique soil type, or a computer dataset of site attributes that may be later downloaded to a microcomputer for further analysis.

SIMS Personal Computer Facilities

SIMS also provides software to transfer, merge, and manipulate soil resource data on personal computer systems. This is shown in the right hand portion of Figure 1. Kermit communications software is used to download soils datasets created via the mainframe SIMS menu selections. A comprehensive file manipulation program allows users to load these datasets to dBase, a popular data base management software system for personal computers. The SIMS dBase program then allows users to open, match and combine fields from various databases to create a new dBase file structure of their own design.

The SIMS Generalized Soil Database (GSDB) expresses major and minor soils data in an efficient, compact format using standard 3-character soil codes ("CanSIS codes"). These soil codes do not in themselves reveal any specific soil information required for various interpretations or applications; they serve as a link to such soil attribute information stored in other dBase files. Several of these global soil attribute files (i.e. The Soil Names File and Soil Layer File) are currently under active development. These files will be used by both the ARC/INFO polygonal GIS and the SIMS cellular GIS. The SIMS dbase File Manipulation Program is designed to allow users to match soil codes from downloaded map areas with the soil attributes of their choice in either of these files. The resulting customized soil attribute databases can then be used directly or compared with additional DLS formatted resource information supplied by the user for the same land area. In this fashion, users will be able to perform their own analysis and correlation of SIMS land resource data with information stored in other databases.

SIMS User Manuals

Two SIMS manuals are currently being prepared for distribution to major agricultural user groups.

The SIMS General User's Manual is intended for land resource specialists who will use the system to extract soil resource information for their own particular needs. Sections of the manual will illustrate how to access the system, the operation of various menu options, and an explanation of various database fields. A diskette containing SIMS dBase File Manipulation programs, as well as associated soil attribute files and Kermit telecommunications software will be included with the manual.

A separate SIMS Systems Manual, containing documentation and listings of all SIMS programming and file maintenance procedures, is also in preparation. This manual is intended for programmers and data managers with responsibility for maintenance or further development of the system.

SUMMARY

The Soil Information Management System (SIMS) has now reached the operational stage. This system is designed to permit resource specialists to conveniently access land resource information from Soil Survey databases for any portion of Agro-Manitoba. Flexible output formats are available, including interactive (immediate) access to any data in the Generalized Soil ("1/4 section") database, and the ability to download selected information to personal computer systems for further analysis. Only limited computer skills are necessary to access and retrieve information from the SIMS mainframe system. A knowledge of personal computers and dBase software is required to utilize SIMS data on a microcomputer.

Development of SIMS is continuing in 1989, including the addition of new database options for detailed soil sampling sites, additional Provincial Soil Testing Lab data, and CLI Agriculture Capability data. Improvements to system access and archive facilities will also be made.

The Canada-Manitoba Soil Survey will provide on-going maintenance and support for the Soil Information Management System. Additional information can be supplied to potential users upon request by contacting the Canada-Manitoba Soil Survey, Rm. 362, Ellis Bldg., University of Manitoba, Winnipeg, MB R3T 2N2.

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GENERALIZED SOIL LANDSCAPE MAP FOR MANITOBA

- Description and Application

G.F. Mills and R.G. Eilers

Canada-Manitoba Soil Survey

Abstract

The Generalized Soil Landscape Map (GSLM) for Manitoba portrays both soil and land information for all of Manitoba at a scale of 1:1,000,000. It depicts natural landscapes as defined by soils, topography and geomorphology. The map is supported by descriptive attributes contained in a computerized data base. The complete array of attributes that describe a particular type of soil and its associated characteristics consist of features such as landform pattern, slope, water table, permafrost and lakes.

The GSLM is designed to meet a variety of needs, both national and regional. A major objective of the map and supporting computerized extended legend is to provide consistent and comparable information about the soil and land required for planning suitable uses for land. The nature of the GSLM data base is described and current and future applications are briefly discussed.

INTRODUCTION

Generalized Soil Landscape Maps (GSLM's) are currently being prepared for all regions of Canada. These maps will provide a standard base with a consistent legend of attributes which are correlated regionally and interprovincially. The soil and landscape information portrayed on these maps is intended for application at a regional, provincial or national level.

The Generalized Soil Landscape Map for Manitoba portrays both soil and land information at a scale of 1:1 million (Canada-Manitoba Soil Survey, 1989). A major objective of this map is to provide comparable and consistent soil and landscape information for the whole of the province. For the most part all of this information is available but in a variety of reports and different scale maps. Although the information on this map is generalized, it is organized in such a way so as to provide groupings or data sets which can be applied at the provincial level for numerous resource evaluations and land use assessments.

The objective of this paper is to describe the nature of the GSLM for Manitoba and the supporting data base. The relationship to soil inventory information available at more detailed scales is also discussed. In addition, some current and future applications of the GSLM data base will be indicated.

SOIL MAP SCALE AND DATA BASE RELATIONSHIPS

Soil maps are made for two general purposes; firstly so that more precise statements can be made about mapped areas in a region than could be made about the region as a whole and secondly so that more general statements can be made about a group of soils than could be made about an individual soil within the group. The mapping process serving the first purpose is termed "subdivision" and that serving the second is "agglomeration" (Mapping Systems Working Group. 1981).

The soil survey data base contains a wide variety of soil information which can be portrayed at various map scales (levels of detail). Common map scales used in Manitoba are 1:125,000 for reconnaissance surveys and 1:50,000 and 1:20,000 for detailed resurveys. Map data at these scales results from subdivision of the landscape. Soil map data shown on more generalized maps such as the GSLM for Manitoba or the Soil Map of Canada result from agglomeration. A comparison of soil and related landscape data portrayed at different levels of generalization is shown in Table 1. Very generalized small scale maps portray polygons covering extensive land areas. The range of soil conditions in these polygons are most appropriately described by the higher categories (Orders and Great Group or phases of these categories) of the soil classification. In contrast, more detailed soil maps (1:50,000 and 1:20,000 scales) describe landscapes at large scales permitting delineation of more precise map units. These map units are commonly defined in terms of soil series or phases of soil series (CSSC 1987). Individual soil series have local place names and are recognized by the properties of their constituent pedons. The hierarchal structure of the Canadian System of Soil Classification is illustrated in Figure 1.

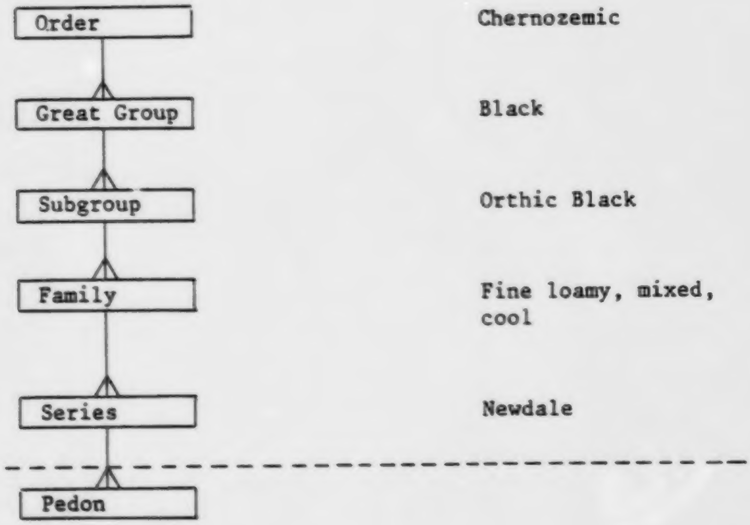


Figure 1. Overview of the hierarchal structure of the Canadian System of Soil Classification

Hierarchal relationships between soil map units at different scales are not as straight forward as the relationships noted in the soil classification. In general, map units of lower intensity surveys will be composed of groups of map units from higher intensity surveys. The lack of coincidence between map unit boundaries shown at different scales results from several factors. The complexity of soils in the landscape requires delineation of precise map units at detail scales, each of which may be a component of more than one map unit from a less detailed survey. In addition, because soil boundaries must be generalized and smoothed on smaller scale maps such boundaries will not coincide with boundaries of their component map units delineated on larger scale map (Mapping Systems Working Group, 1981).

There are many different soil data bases in soil science. Disciplines such as soil chemistry, soil physics, soil microbiology, soil fertility, soil classification, soil mineralogy and soil survey each have data bases differing in content and specificity (Arnold 1984). The characteristics of each data base determine the appropriate scale or level of detail for presentation.

Soil data bases can be manipulated and managed at more generalized scales but there is a masking effect when data is used at a different scale than that at which it was collected. Geographic aggregation of soil map data increases the heterogeneity of the data and often masks larger scale relationships between data sets. The extent to which data may be masked is noted in the scale change on progressing from the more detailed 1:20,000 and 1:50,000 scale soil maps to the reconnaissance soil maps at 1:125,000 scale and then to the less detailed GSLM or the Manitoba portion of the Soil Map of Canada (Table 1). The entire range of soil, landscape and climatic conditions across Manitoba as shown by a very large but unknown number of map units at more detailed scales can be represented by just 414 polygons on the GSLM or 53 polygons on the Soil Map of Canada. Obviously much of the available detailed soil information has been lost through generalization. The disadvantages of information lost in this way can be balanced off against the benefits gained from a consistent map scale for the entire province. This premise is operative for any land area that is selected for resource analysis, planning or development. The benefits of working with a complete and consistent data base described by uniform criteria and defined according to standard parameters are obvious. In many cases, generalization of data to a smaller scale for which a complete and standardized data set can be developed is the only way that these advantages can be achieved.

DESCRIPTION OF THE GSLM, MAP UNITS AND LEGENDS

The Generalized Soil Landscape Map of Manitoba was prepared to provide consistent and comparable information about the soil landscapes for the entire province. A soil landscape includes the full array of attributes that describe a distinct type of soil and its associated characteristics such as landform, slope, water table, permafrost and lakes. Compilation of the map was done by standard methods. The map is divided into unit areas called polygons, each of which is described in terms of a standard set of attributes. These attributes are the factors considered most important for plant growth, general land management and terrain sensitivity. A polygon may contain one or two distinctive soil

Table 1. Comparison of Soil Information Portrayed at Various Map Scales

Type of Map	Map Scale	Soil Classification	Map Unit Complexity	Number of Polygons			Comments
				In Agro Man.	Manitoba Total	in $100km^2$	
Generalized Small Scale Maps			Highly Heterogenous				
Soil Map of Canada	1:5M	Orders Great Groups		39	53		Polygons cover extensive land areas; relatively few polygons described by only few attributes
Agroecological Resource Area Map (ARAM)	1:2M	Orders Great Group		50	-		
Generalized Soil Landscape Map (GSLM)	1:1M	Great Groups Subgroup	Increasing Aggregation of Map Data	205	414		
Reconnaissance Scale Map[1]	1:125K	Association of Subgroups				a) 7 b) 15	Polygons represent increasing smaller land areas; relatively many polygons described by many attributes
Detailed Scale Maps[2]	1:50K	Soil Series				a) 135	
	1:20K	Soil Series	Highly Homogenous			b) 201	

[1] Soil Survey of South-Central Manitoba (1943) a) TWP1 RGE 6W
b) TWP4 RGE 5W

[2] Soils of the R.M. of Grey, Differin, Roland, Thompson and part of Stanley - D60 (1988) a) TWP1 RGE 6W
b) TWP4 RGE 5W

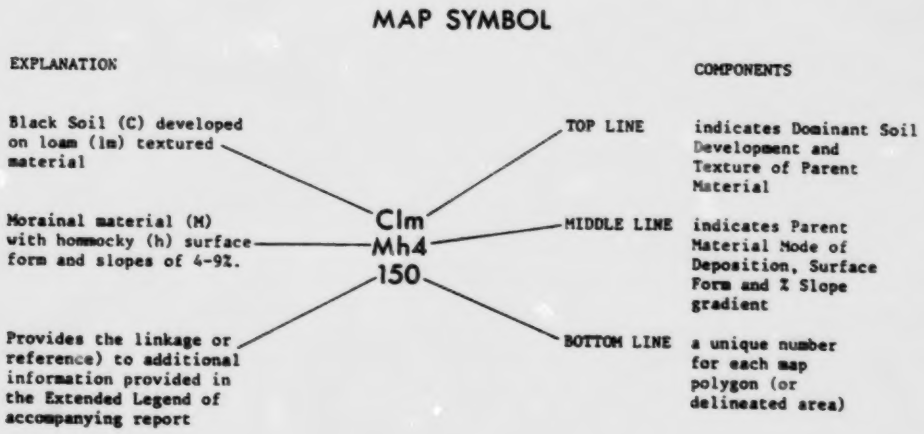
landscapes as well as up to four smaller but contrasting conditions which are described as inclusions.

Soil and land attributes are recorded for the dominant (>40%) and subdominant (>15%) soil landscapes found in each polygon. This information is made available in three ways: the map itself, the extended legend included at the back of the report accompanying the map or the detailed computerized legend available separately.

Map Legend - The symbols on the map and the accompanying map legend describe only the attributes of the dominant soil landscape for each polygon. The attributes are:

- soil development (taxonomy or class of soil)
- texture of parent material (PM)
- mode of deposition (or origin) of parent material
- surface form
- slope gradient
- kind of rock outcrop
- unique polygon number

The attributes describing each polygon are arranged in the map symbol as shown in Figure 2. There is one map symbol for each polygon. The map legend explains the abbreviation used in the top and middle lines of each map symbol. The top line specifies the soil development and texture of the polygon. The colour of each map polygon reflects soil development. Three shades of this colour are used to indicate the various textures - lighter shades are used for sand and sandy loam textures, intermediate shades for the loams and clay loams and the darker or more intense shades are used for the clays. The middle line indicates origin of parent material, surface form and slope gradient. The bottom line indicates the unique polygon number as a reference to additional information contained in both the extended legend and the computer legend.



Black Soil (C) developed on loam (lm) textured material

Morainal material (M) with hommocky (h) surface form and slopes of 4-9%.

Provides the linkage or reference) to additional information provided in the Extended Legend of accompanying report

indicates Dominant Soil Development and Texture of Parent Material

indicates Parent Material Mode of Deposition, Surface Form and % Slope gradient

a unique number for each map polygon (or delineated area)

Figure 2. Explanation of Map Symbol

The attributes shown in the map symbols and legend serve to differentiate one polygon from another. They were chosen for the following reasons:

- soil development	because it is indicative of natural fertility internal drainage, alkalinity and acidity
- texture of parent material	because of its influence on the capacity of the soil to store moisture and to make moisture available to plants and in the case of sandy soils, on their susceptibility to wind erosion
- mode of deposition of parent material	because it provides information on the surficial geology and a linkage to mapping methods used on the source map
- surface form	because of its influence on soil development, land use, and surface water drainage
- slope gradient	because of its influence on land use and water erosion risk
- kind of rock outcrop	because of its influence on the chemistry of the drainage water and on plant or aquatic growth

Extended Legend - A brief report and guide to understanding Soil Landscape Maps is included with the map. The extended legend in the back of this report describes for each polygon, the attributes of the dominant and subdominant soils and important nonsoil feature such as rock outcrops. It includes the attributes shown on the map plus the following attributes:

- calcareous class
- drainage class
- surface texture
- depth to water table
- type of compacted, consolidated, or contrasting layer
- depth to compacted, consolidated or contrasting layer
- slope length
- brief attributes for inclusions

Detailed Computerized Legend - Additional attributes required for more specialized assessments and interpretations are stored in the computer files of the Canada Soil Information System (CanSIS). These attributes will not be published with the maps and reports. They will, however be available on floppy disk with d-Base III data structure and supporting documentation. The computerized legend includes the following attributes:

- polygon number
- kind of surficial material
- percentage distribution of material
- grid code for locating polygons
- regional landform
- local surface form
- slope gradient class
- slope length
- parent material origin
- parent material texture
- surface texture of mineral soil to 15 cm
- coarse fragment content in control section
- rooting depth
- compacted, consolidated or contrasting layer
- depth to compacted, consolidated or contrasting layer
- drainage
- available water-holding capacity in upper 120 cm
- depth to water table
- dominant type of ice
- ice content
- permafrost occurrence
- depth of active layer
- patterned ground
- pH of upper 15 cm surface mineral horizon ($CaCl_2$)
- pH of upper 15 cm surface mineral horizon (water)
- organic carbon content of surface horizon to a maximum of 15 cm
- nitrogen content of surface horizon to a maximum of 15 cm
- thickness of humus layer
- calcareous class of parent material
- inclusion I
- inclusion II
- vegetation cover class
- lake size
- water bodies, percentage occupance of polygon
- reliability class
- complexity class
- soil name I
- soil name II

These attributes are indicated for both the dominant and subdominant (where present) portions of the polygon.

Polygon Description - Polygons may delineate both simple or relatively complex soil landscapes. When a polygon was found to contain very different types of soil or an important inclusion, the two most prominent soil landscapes are described, as well as the inclusion. The proportions of dominant and subdominant soil landscapes and inclusion in any one polygon are as follows:

One soil landscape, without or with an inclusion	Dominant represents nearly the entire area (100%). If an inclusion is present assume the dominant soil landscape to represent 90% and the inclusion 10%.

Two soil landscapes	Assume the dominant soil landscape to represent 70% and the subdominant soil landscape 30%.
Two soil landscapes and an inclusion	Assume the dominant soil landscape to represent 60%, the subdominant soil landscape 30% and inclusion 10%.

Map Compilation - Polygons for the soil landscape map were drawn and described by generalizing information from all available soil maps. Where no soil maps existed, supplementary data from surficial geology and biophysical maps were used. This data was extrapolated by interpretation of air photos and satellite imagery.

Map Reliability - Reliability varies from one part of the map to another, primarily due to differing scale and detail level of available base line soil information. A general guide to the reliability of the information is provided as a small inset on the soil map. A reliability rating of the information for each polygon is also provided in the detailed computerized legend.

Information Updates - As new information becomes available, usually when a soil map for a previously unsurveyed area is produced, the attributes for the soils in that area will be updated. Eventually the soil landscape boundaries will be revised. The revisions will initially be recorded in the computerized data base stored in CanSIS. New maps will not regularly be published so the information maintained in CanSIS will be kept more up-to-date than the published maps. The most current versions of both the map and soil data bases can be supplied to users on request.

APPLICATIONS

The GSLM and information contained in the detailed computerized legend allow for the production of soil landscape information in a variety of ways. Basic information derived directly from the GSLM data base can be highlighted as single factors or combinations of factors. To-date single factor maps have been produced for soil texture, parent material and the distribution of organic soils.

Soil and landscape attributes relevant to a particular interpretation can also be extracted and manipulated according to algorithms or models developed to derive that interpretation. A series of soil degradation themes have been completed - soil erosion risk due to wind (Coote et.al. 1989), soil erosion risk due to water (Eilers et.al., 1989) and soil salinity (Eilers, In Press). Computerized files of attributes were compiled to supplement data contained in the GSLM detailed computer legend for input to algorithms such as the universal soil loss equation for predicting soil erosion by water. Maps showing Soil Sensitivity to Acidification and the Potential for Soil and Bedrock to Neutralize Acid Deposition (Wotton and Haluschak, 1986) have been produced for provincial input to a national study of the impact of acid rain. A surface soil pH map of Agro Manitoba was recently compiled from the GSLM data base supplemented with data from the Provincial Soil Testing laboratory and the soil survey daily file (Haluschak, 1989).

A major land evaluation project utilizes the GSLM as the soil data base for productivity assessment of Manitoba agricultural soils (Onofrei 1989). An Agroecological Resource Area Map (ARAM) for Manitoba at a 1:2,000,000 scale is being generalized from the GSLM to provide input to a Prairie Region Land Evaluation study. Both of these land evaluation studies are supplemented by climatic data from Atmospheric Environment Service files in order to assess soil productivity for Manitoba and for the prairie region. The feasibility of utilizing generalized polygons on the ARA map to stratify Agro Manitoba into risk areas for production of grain and forage in support of the crop insurance program is also being investigated.

The distribution of soil textural characteristics shown on the GSLM has been used as a base to evaluate soil moisture conditions in Agro Manitoba. Soil moisture status at the end of the growing season has been modelled for broad soil landscapes using appropriate meteorological data combined with soil texture characteristics (De Jong and Shields, 1988).

There are many potential applications of the GSLM data base which remain to be developed. A generalized map of the province showing soil engineering properties is in preparation. Assessment of potential productivity over large areas for individual crops such as wheat, oil seeds and forages will be derived as specific algorithms to model the growth of these crops are developed.

Delivery of farm management programs dealing with specific soil conditions and problems can be facilitated using the GSLM data base. For example, the GSLM polygon in the Marquette area describes extensive but variable soil salinity, high water tables and groundwater discharge. Polygons along the Manitoba Escarpment and in steeply sloping upland portions of western Manitoba have common concerns related to potential erosion by water. The polygon containing the shallow sandy soils of the Almasippi association presents management concerns related to high water table, potential for groundwater polution and potential risk of erosion by wind. The management concerns of these and similar soil landscapes can be identified and located on the GSLM and specific management packages developed to focus on their needs.

The GSLM provides broad scale soil landscape information required to model the impact of climatic change on productivity of the land resource. Increasing variability of weather pattern in recent years and uncertainty about global climatic change has generated much interest in assessing the impact of such environmental change on agriculture, forestry and wildlife.

One of the more important applications of the GSLM will be to provide a broad stratification within which more detailed planning needs can be focussed and additional data collected as needed. The GSLM thus serves as a ready reference to other map and land resource data at larger scales.

SUMMARY

The Generalized Soil Landscape Map project for Manitoba was initiated in 1980. The map depicts natural landscapes as defined by soils, topography and geomorphology at a scale of 1:1,000,000. The main product of the GSLM project is a digitized map and supporting data bases maintained on computer file. Initially the map was expected to serve mainly for extension, public relations and education purposes. As experience has been gained in working with this data base, it has become apparent that it will serve several other very practical purposes as well.

The GSLM information can be used as a base for productivity assessment of land at the national or regional level. It has been used to identify areas that have actual or potential problems affecting land quality such as salinity and susceptibility to erosion. It will be used to locate general areas that may be suitable for particular types of land use and which can be ear-marked for more detailed investigation. It can provide baseline data useful for environmental impact studies or assessment of climatic change on the productivity of large land areas. Finally, the GSLM will have applications in the education of students of soil science and geography at colleges or universities.

The GSLM experience has pointed out the advantages of having access to uniform, standardized and comparable soil information for large land areas. This data base provides the only complete set of soil and land resource information for the entire province. However, the main product of the GSLM project is not the hard copy map and report, but rather the digitized map information and the supporting data bases maintained on computer file. The hard copy map and extended legend is only a "snapshot" of the data base fixed in time in 1988.

The GSLM for Manitoba has evolved over a time period characterized by rapidly developing automated data handling technology. At the same time, users of soil survey data are becoming more sophisticated in the way they wish to access and use soil data for their own programs. The computerized soil data base developed for the GSLM and similar, but more detailed data bases being developed to back up ongoing inventory projects are undoubtedly the way of the future.

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RELIABILITY OF SOIL DATA DERIVED FROM MAPS AND LEGENDS FOR AGRICULTURAL LAND EVALUATION STUDIES

C. Onofrei[1], M. Langman[2], and J. Dumanski[1]

[1]Land Resource Research Centre and
[2]Manitoba Soil Survey

EXECUTIVE SUMMARY

All agricultural land evaluation studies use models of some type to estimate the behavior of complex agroecosystems of which soil is a major part. Since most of the models developed for land evaluation quantify the output (yield) of different agroecosystems within a large region of interest, for practical reasons they must rely on available soil resource data as derived from maps, legends and pedon files.

The reliability of predictions by numerical models depends in large extent on the accuracy and precision of soil input data. In effect, unreliable soil data will impact negatively on any interpretation of land use regardless of the objective of the study (agricultural production, forest suitability, soil conservation or environment protection), the method used in the analysis (statistical or simulation), the model type or its complexity.

The mapping process describes a dynamic system in nature. In a purely theoretical sense, the values derived from soil inventory data are variables; quantities that vary with time. For practical reasons, however, many soil characteristics are treated as parameters; quantities that are not true constants but that can be kept as constants within a given calculation or for a model run. For characteristics that change at a very slow rate, this assumption is not critical. The implication of substituting these variables with their equivalent parameter values is minimal when describing the function of an agroecosystem. However, the inherent variability of soil in space cannot be ignored, and the statistical meaning of soil parameters, i.e. population characteristics must be considered.

Since the mapping process is not an extensive experiment, the value associated with a given soil characteristic is not a true parameter. At the same time soil resource inventories collect data for a wide range of applications. Some times this data can be somewhat meagre. Although soil survey institutions endeavor to provide accurate and precise soil data, the user has the final responsibility to ensure an adequate data set for his particular problem. In the present study the attention was focussed on the reliability of soil resource inventory data for land evaluation studies involving crop yield.

The quantitative evaluation of land within a large region starts with three fundamental interrelated assumptions:

1. Soils within an area of interest were aggregated into reasonably accurate map delineations,

2. The dominant Soil Series identified is an appropriate population to be considered as representative within each delineation,

3. Reliable Soil Series parameters can by derived from the existing soil inventory documents (maps, legends, pedon files).

The purpose of this study was to evaluate the validity of the three aforementioned assumptions. This was achieved by converting these three assumptions into null hypothesis (Ho) to be tested statistically. Beyond this the process involved: identification of the parameter(s), establishing the null hypothesis, selecting a null value, and posing alternative hypothesis. Other requirements included selection of an appropriate test statistic, description of the experiment performed (field and laboratory analysis) in order to evaluate the test, calculation of the test, and presetting the results upon which to base the decision as to whether or not to reject the null hypothesis.

This paper refers to the statistical tests concerning the reliability of the indicated proportions of named Soil Series, all agronomic attributes considered together, and individual attribute (slope, drainage, contrasting layer, horizon description, and profile texture). The null value of the individual parameter was derived from the map and legend.

A field investigation was conducted on 19 randomly selected soil map delineations within the Rural Municipality of South Norfolk in South Central Manitoba. A set of 10 random inspection points were located within each delineation, giving 190 random sites throughout the study area.

Three possible interpretations pertaining to map unit composition were tested:

i) 100% purity,

ii) 85% purity, as the target set by the Canadian Soil Survey Committee, and

iii) At least 65% purity, as set by the guidelines of the Soil Mapping System Working Group (SMSWG).

The Z - test was used to evaluate the proportion of named Soil Series. Although decisions made were based on a level of significance $\alpha = 0.01$, the results were reported in terms of P-value. This is the smallest level of α at which the data is significant, in other words the smallest value of Type I error (the probability of rejecting a true Ho or rejecting the parameters developed from map/legend). Since the P-value shows how significant the data is in relation to the null hypothesis posed, other users of similar soil data may interpret the results differently.

The test results are summarized as follows:

1.) At $\alpha = 0.01$, the Z - test results suggested rejection of the 100% purity claim as well as the 85% purity claim.

2.) The results confirm that the map is at least 65% pure. Therefore the purity of the map with respect to proportion of named Soil Series is within the limits established by the SMSWG, which is in effect the operational system used for mapping soils in the field.

3.) Compound map units were more accurately mapped (P=0.9582 and P=0.9177 for dominant and significant components, respectively) than were simple map units (P=0.0174). For compound map units the Ho would hold true for almost any level of α.

4.) For individual delineations, with one exception, the hypothesis that the Soil Series adequately represents at least 65% of the unit was accepted at $\alpha = 0.01$. For most units the Ho holds true at a significance level of $\alpha = 0.05$ and even higher.

Two claims were considered in the evaluation of the extent of the agreement/disagreement between observed and mapped agronomic attributes:

> i) The selected agronomic attributes agree with field observation in at least 85% of the area or do not strongly disagree for more then 15% of the area (a target claim), and
>
> ii) The selected agronomic attributes agree with field observation in at least 65% of the area and do not strongly disagree for more than 15% of the area (a claim derived from the SMSWG guidelines).

Each statement is a two part claim in the sense that two separate tests must be performed, one for agreement and one for disagreement, and the results must be interpreted in relation to each other.

The statistical test for the proportion of agronomic attribute(s) followed the so called "Ground Truth Criteria" method which emphasizes the degree of the difference between the observed (field) and expected (map/legend) value using a score procedure. This method is based on the calculated confidence limits (upper and lower) expressed in terms of Minimum number of Successes (Min.S) and Maximum number of Failures (Max.F) of a binomial sample of a given size.

The test results are summarized as follows:

1.) The Ho associated with the target claim for both map unit types as well as for the entire map was rejected due to the lack of agreement; the numbers of Observed Successes (Ob.S) were smaller than the Minimum number of Successes (Min.S) required to accept Ho, i.e. 76 (Ob.S) < 103 (Min.S), 42 (Ob.S) < 46 (Min.S), and 111 (Ob.S) < 152 (Min.S).

2.) The Ho associated with the claim developed from the SMSWG guidelines was accepted for slope, drainage, contrasting layer and profile texture as well as for all attributes considered together. For horizon description the Ho was rejected for simple map units and for the entire map due to the large percent of disagreement; the numbers of Observed Failures (Ob.F) were larger than the Maximum number of Failures (Max.F) imposed by the Ho, i.e. 36 (Ob.F.) > 27 (Max.F), and 42 (Ob.F.) > 38 (Max.F).

It appears that detailed horizon descriptions that are more concerned with taxonomic classification than with characterization of agronomic attribute are not very reliable. However, this study indicates that data sets derived from soil maps and legends provide reliable information that can be used with confidence for agricultural land evaluation studies.

APPLICATION OF PIXMOD FOR AGRICULTURAL LAND EVALUATION

C. Onofrei and J. Dumanski
Land Resource Research Centre
Agriculture Canada

EXECUTIVE SUMMARY

Agricultural land evaluation is an open-end activity. The number of land use planners and land use managers that require information on land is very large, and their objectives are variable. A quantitative land evaluation study that provides answers to all possible questions posed by land users is only a theoretical possibility. However, for a land evaluation study to be successful, that is to be used, it must provide general information that can be easily reformatted to answer more than one specific question.

In this study land evaluation research has focused on providing answers to questions like: **"For a given MANAGEMENT INPUT, which LAND AREA(S) offers the greatest advantage for growing WHEAT in Manitoba ?"** The "advantage" was expressed in agronomic terms i.e. marketable yield per unit of land area. The problem of agricultural land evaluation was approached from the standpoint of productivity (yield) of the agricultural system. The concepts of agroecosystem, crop growth simulation, and prediction of yield in terms of probability, were employed. Although the paper deals primarily with application of PIXMOD, a physical model developed for land evaluation within the Canadian Prairies, two other problems highly related with this approach are also considered: the identification of the Agroecosystem represented in the model and the manner in which the agroecosystem output is presented, that is Yield Prediction.

The Agroecosystem. The agroecosystem is defined as a relatively homogeneous three-dimensional soil tract, with uniform crop distribution , driven partly by man-controlled inputs (farm, goal oriented system), and partly by natural environment inputs (atmosphere and geology systems). In this study, the Soil Series was chosen as the most appropriate unit to represent the soil system, and wheat (Triticum aestivum, L.), spring variety, which is the major agricultural commodity of the Canadian Prairies, was selected as the representative crop in the region.

Yield Prediction. The climate within the region of interest determines what crops are grown or can be grown, whereas weather particular to each growing season is the major controlling factor of crop yield. Since weather elements are generated by stochastic processes, it is valid to say that the output of an agroecosystem is uncertain and that yield can only

be calculated retrospectively, when the weather elements over the complete growing season are known. The expected yield or mean value is an important parameter that describes the yield population but frequently, land users require information about the variability of wheat yields. In this circumstance it is more realistic and also more useful that land evaluation activities focus on information that permit users to place betting odds, i.e. probability, upon yield. Simulation models that can be run repeatedly with annual historic weather records can provide informative measures of yield variability. PIXMOD was utilized in this fashion for Manitoba soils using 20 years of weather data.

The practicality and utility of information provided by this approach, is illustrated using the results obtained for 27 selected agroecosystems from Manitoba. Statistical analysis performed on the annual yield series for 20 years suggested that wheat yield populations are not all normally distributed; some are skewed, others are heterogeneous populations. Since many conclusions of land users are based on normal distributions the data was transformed and the wheat yields were finally described by a family of normal probability functions.

The yield probability distribution curves indicate a clear difference among the agroecosystems analyzed, that could not have been established by comparing mean yields alone. The wheat yield distributions differ not only in terms of location (μ), but they differ fundamentally in terms of scale (σ), and shape, or a combination of all three parameters.

The development of the yield probability density functions opens up numerous avenues for land system evaluation. To illustrate this, using the Generalized Soil Landscape Map as a basic geographical display of soil distribution and the developed wheat yield probability functions, five different maps were formed as follows:

1.) Break Even Wheat Yield Risk Map of obtaining 1783 kg/ha or lower (the "break even" yield calculated at the cost of inputs and the price of wheat estimated for Manitoba in 1987) for an average management level,

2.) Break Even Wheat Yield Risk Map of obtaining 1783 kg/ha or lower for an improved management level,

3.) Break Even Wheat Yield Risk Map of obtaining 1168 kg/ha or lower (the "break even" yield calculated at the cost of inputs and the price of wheat estimated for Manitoba in 1985) for an average management level,

4.) Profitable Wheat Yield Map of obtaining 3343 kg/ha or higher (the yield required to cover the total cost, operation and fix cost, at the input costs and the price of wheat estimated for Manitoba in 1987) for an average management level, and

5.) Profitable Wheat Yield Map of obtaining 3343 kg/ha or higher for an improved management level.

It should be pointed out that for each of the above maps the land areas rank differently when the reference yield chosen for comparison is changed. Similar analysis/maps, using different reference yields can be performed for many other scenarios. The use of such reference yields (the limit of integration of probability functions) and the resultant probabilities can be used to identify areas with comparative production advantages, or conversely areas for agricultural strategies and support policies to better manage production risks.

Other useful information can be derived from the probability density functions. For example, land can be evaluated in terms of reliability of yield, the risk of a given undesirable yield, the yield necessary to amortize a given level of investment, and so on. Similarly by varying the management inputs, land areas with different soils could be compared relative to fertilizer response and return to investment. Also by altering the weather inputs comparisons could be made to predict the economic impact of climate change. In summary, this technique enables comparisons of land areas to be made for a wide range of social and/or economic constraints faced by the land use planners and/or land use managers.

SURFACE SOIL pH MAP OF MANITOBA

P. Haluschak

Canada-Manitoba Soil Survey

INTRODUCTION

Soil reaction (pH) is an indication of the acidity or alkalinity of the soil and is measured in pH units. pH is defined as the negative logarithm of the hydrogen ion (H^+) concentration. The pH scale ranges from 0 to 14 and each increment of the scale is a 10 fold difference in concentration. A soil with a pH of 7 is said to be neutral, while values of less than 7 are acid and values greater than 7 are alkaline.

Soils become acid when considerable portions of the exchangeable cations are hydrogen and various forms of hydrated aluminum. Hydrogen ions in the soil solution are derived from carbonic acid which is formed by the combination of carbon dioxide and water. Carbon dioxide is produced mainly by respiration of plants roots and aerobic decomposition of soil organic matter by soil micro-organisms. Nitrification of nitrogen fertilizers and plant residues is also a source of acidity.

The presence of limestone or carbonate can increase or maintain alkaline soil conditions as a result of the release of hydroxides and the adsorption of hydrogen ions by carbonates. A soil with free carbonates provides a tremendous reserve of buffering capacity and pH is likely to remain above 7.5 until all free carbonates are dissolved or leached out of the soil.

Plants normally grow well in soils which have a pH range of 5 to 8.5. Strongly acid soils are undesirable because of toxic levels of soluble aluminum and greatly reduced microbial activity. Strongly alkaline soils result in lower micronutrient availability, except for molybdenum. Particularly, iron, manganese, copper, zinc and the macronutrient phosphorus may occur in deficient levels.

High soil pH conditions can cause some herbicides to remain active in the soil for longer periods. This can cause problems with rotations which include sensitive crops. A sulfonyl urea herbicide, Glean, is registered for use only on soils having a pH of 7.5 or less. On soils with a pH of less than 7.5, only wheat may be seeded the year following the application. If the soil pH is 7.0 or less either wheat or barley may be seeded the year following the application. To assist in making recommendations for the use of herbicides which are sensitive to pH, a general assessment of surface pH in the agricultural area of Manitoba was undertaken.

METHODS

Soil pH values for surface layers which ranged in thickness from 15 to 20 cm were selected. The pH values are equivalent to pH measured in 1:1 soil-water suspension. Approximately 5000 pH values from soil survey data files and 90,000 pH values from soil test files were examined.

pH values were grouped into soil units using a generalized soil landscape map(1). Values of soil pH in each soil landscape unit were sorted into three classes.

A - pH less than 7.1
B - pH 7.1 to 7.5
C - pH greater than 7.5

The distribution of soil pH values in each class for all map units was calculated as shown by the following example.

Map Unit 75	pH Class			
	A	B	C	Total
Number of Samples	21	124	477	622
%	3.4	19.9	76.7	100

Map Unit Symbol = $C^8 B^2$

Percentile proportion of samples in each pH class was assumed to represent an equivalent area of cultivated land in the map unit. Map units with similar distributions of soil pH were combined into larger areas to produce a generalized map (Figure 1).

RESULTS AND DISCUSSION

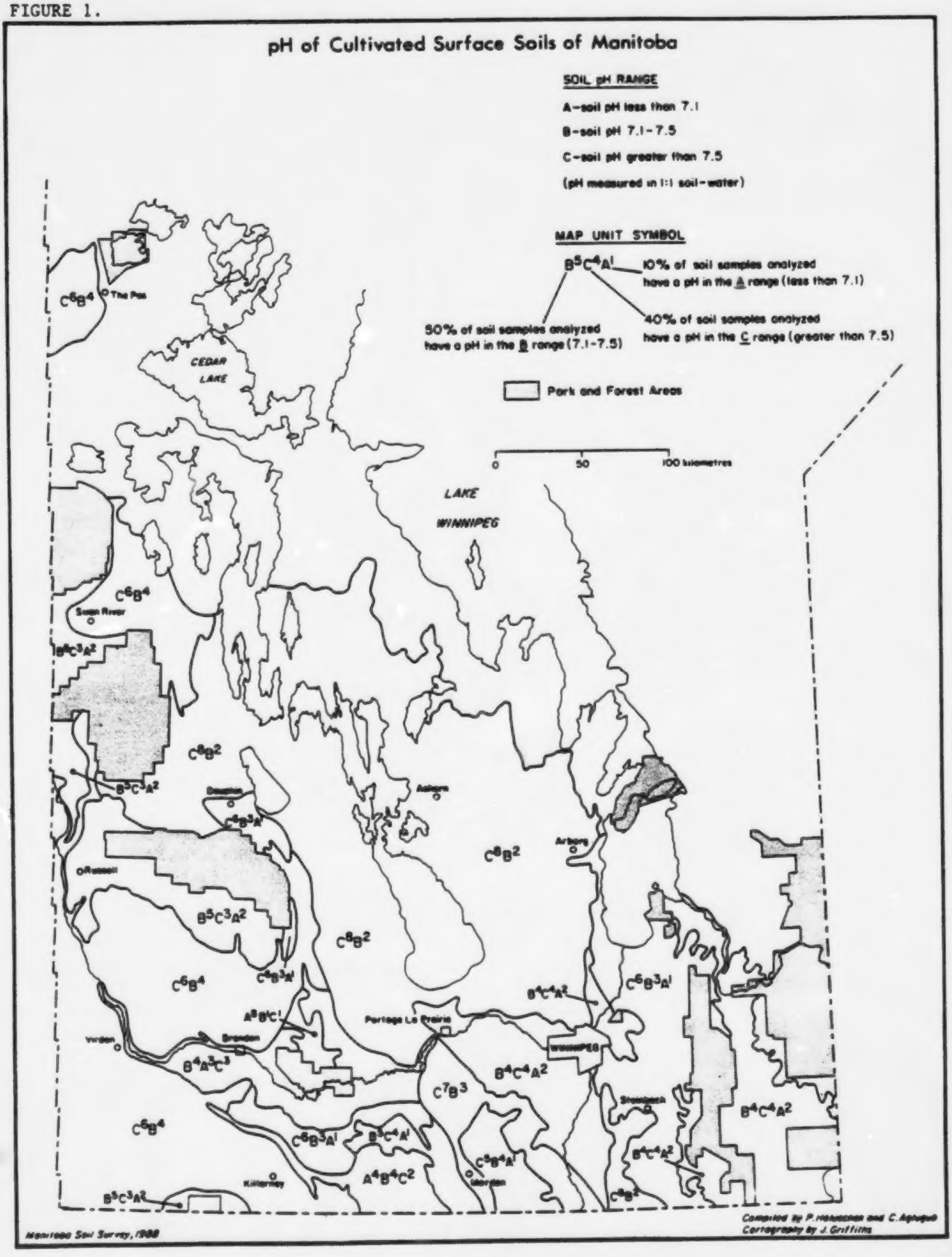
Soil pH Variability

Soil pH can fluctuate, seasonally at a given site, by as much as 0.5 pH units(2). This variability which is due mainly to temperature, aeration, biological activity and salt concentration is relaitvely stable over the long term.

In addition there is spatial variability in soil pH of almost one pH unit in undulating and in level soil landscapes (Figure 2 and 3). Erosion and cultivation of knolls and upper slopes can result in the incorporation of free carbonates from the subsoil into the surface layer, therefore, higher pH values are present at these topographic positions. More developed and leached profiles downslope are reflected in lower pH values, however, high pH values may occur in depressional areas whenever salts and carbonates are brought to the surface by groundwater in soils with high water table levels.

Similar variability in soil pH can be encountered on nearly level landscapes (Figure 3). The extent of drainage and leaching and depth of cultivation are important factors in determining the amount of carbonates in the surface layer. The absence or presence of carbonates will result in acid or alkaline soil conditions.

FIGURE 1.



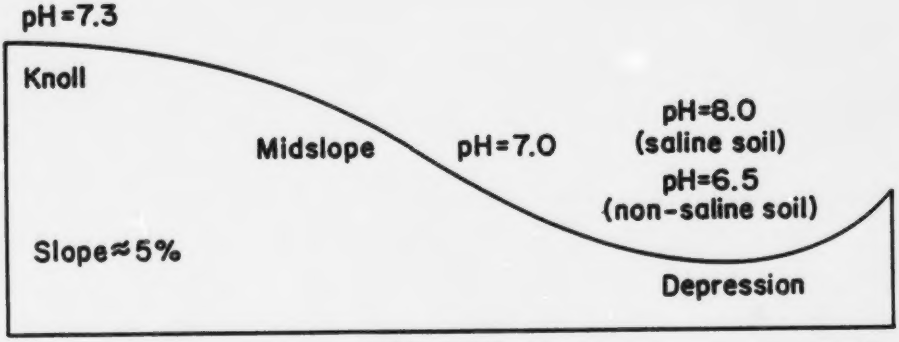
pH of Cultivated Surface Soils of Manitoba

SOIL pH RANGE
A–soil pH less than 7.1
B–soil pH 7.1–7.5
C–soil pH greater than 7.5
(pH measured in 1:1 soil–water)
MAP UNIT SYMBOL
$B^5C^4A^1$
10% of soil samples analyzed have a pH in the A range (less than 7.1)
50% of soil samples analyzed have a pH in the B range (7.1–7.5)
40% of soil samples analyzed have a pH in the C range (greater than 7.5)
Park and Forest Areas
0
50
100 kilometres
The Pas
C^6B^4
CEDAR LAKE
LAKE WINNIPEG
C^6B^4
Swan River
$B^5C^3A^2$
C^8B^2
$B^5C^3A^2$
Dauphin
$C^6B^3A^1$
Ashern
C^8B^2
Arborg
Russell
$B^5C^3A^2$
C^8B^2
C^6B^4
$C^6B^3A^1$
$A^5B^4C^1$
$B^4C^4A^2$
$C^6B^3A^1$
Portage La Prairie
Virden
Brandon
WINNIPEG
$B^4A^3C^3$
C^7B^3
$B^4C^4A^2$
Steinbach
$B^4C^4A^2$
C^6B^4
$C^6B^3A^1$
$B^5C^4A^1$
$C^5B^4A^1$
$B^4C^4A^2$
$A^4B^4C^2$
Killarney
Morden
$B^5C^3A^2$
C^8B^2

Manitoba Soil Survey, 1988

Compiled by P. Haluschak and C. Aglugub
Cartography by J. Griffiths

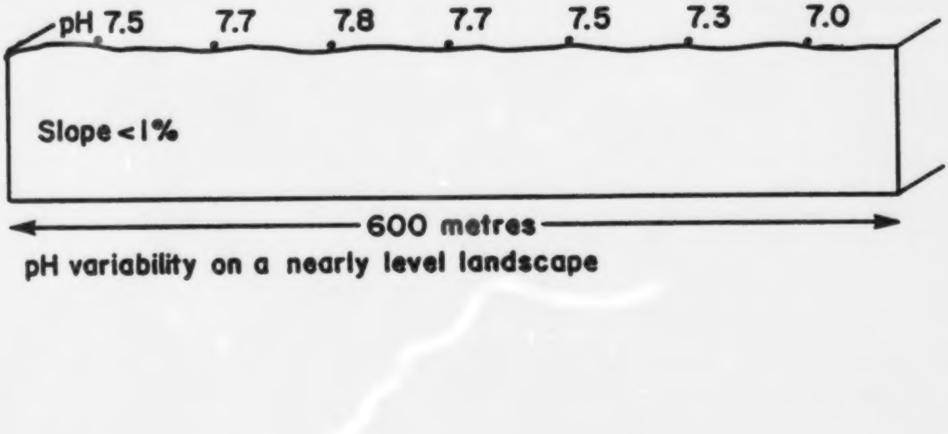
FIGURE 2.


pH=7.3
Knoll
Midslope
pH=7.0
pH=8.0
(saline soil)
pH=6.5
(non-saline soil)
Slope≈5%
Depression

300 metres

pH variability on an undulating landscape

FIGURE 2.


pH 7.5
7.7
7.8
7.7
7.5
7.3
7.0
Slope<1%
600 metres

pH variability on a nearly level landscape

Soil pH Distribution in Manitoba Soils

Soils of the Interlake and Westlake region are alkaline with pH values greater than 7.5 in most surface soils. These areas are identified as C^8B^2 on the map (Figure 1). Soils of this region are developed on extremely calcareous till and lacustrine deposits, as a result, shallow profile development occurs and carbonates are present in the surface layer of most soils. Average soil pH values for these areas are 7.8 (Table 1).

Table 1

Map Symbol	Average pH
C^8B^2	7.8
C^7B^3	7.7
C^6B^4	7.6
$C^6B^3A^1$	7.6
$C^5B^4A^1$	7.6
$B^5C^4A^1$	7.4
$B^4C^4A^2$	7.4
$B^5C^3A^2$	7.4
$B^4A^3C^3$	7.3
$A^4B^4C^2$	7.1
$A^8B^1C^1$	6.5

S.D. $\pm$ 0.4

Extensive areas of alkaline soils, C^6B^4 and $C^6B^3A^1$, with average pH values greater than 7.5 are present above the Manitoba escarpment (Figure 1, and Table 1). Soils with pH values less than 7.5 account for about 40% of the area.

The Parkland regions, $B^5C^3A^2$, contain soils which show a greater degree of leaching and removal of carbonates due to more favorable moisture conditions. The average soil pH tends to be lower than 7.5 in these areas.

Although many map areas contain some slightly acid soils (pH less than 7.1) only one map delineation, $A^8B^1C^1$, was identified in which most soils are slightly acid with an average pH of 6.5 (Figure 1, Table 1). The surface texture varies from loamy sand to clay loam but is predominantly loam. Generally, these soils are well drained and the surface layer is free of carbonates.

SUMMARY

The variable nature of soil pH will require intensive sampling to accurately assess the surface pH condition of a particular field.

Approximately 88% of the cultivated surface soils in the agricultural area of Manitoba are alkaline in reaction. Cultivated soils with a surface pH greater than 7.5 account for about 48% of the agricultural soils. Acid soil conditions represent about 12% of the agricultural area.

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SOIL PROFILE CHARACTERISTICS ON A SODIUM AFFECTED LANDSCAPE IN CENTRAL NORTH DAKOTA

B. D. Seelig and J. L. Richardson, North Dakota State University.

ABSTRACT

A systematic approach was used to analyze soil characteristics in relation to the important elements of the landscape. A more concise understanding of the evolution of sodium affected soils and landscapes in central North Dakota is essential. An overall landscape model relating taxonomic composition to the processes of soil formation could then be used to resolve problems of classification and mapping unit definition. A segment of the landscape in a sodium affected area in east-central North Dakota was selected for detailed analyses of soil properties with respect to landscape position. Three landscape positions with distinctly different soil compositions were identified using standard methods of soils description and classification. Laboratory analyses of soil samples, vegetation composition, and water table levels substantiated landscape-soils relationships based on morphologic observations. Regression analysis of the cambic and natric horizons related water dispersible clay (WDC) to sodium adsorption ratio (SAR), and electrical conductivity (EC). Data stratified by landscape position reflected the influence of moisture regime on natric soil properties. We conclude that moisture regime should have a larger influence on the classification of these natric soils.

INTRODUCTION

The processes of sodic soil evolution as proposed by Gedroits were used to explain and define natric (Solonetz) soils in North Dakota (Kellogg, 1934). Based mainly on morphologic features observed at various sample locations, a cycle of natric soil formation and destruction was proposed to explain these soils. A shallow water table is considered a primary prerequisite for the initial phase of the cycle, because it provides the vehicle for convective movement of soluble salts into the soil horizons via capillary rise of water. This process also accounts for the heterogeneity of these soils due to the effect of textural and structural differences on the movement of water.

Whittig and Janitzky (1963) confirmed the topographic influence on natric soil development, when they demonstrated differential ionic movement along a sodium affected landscape in California. Pronounced microrelief exhibiting obvious differences in soil properties is common to areas of natric soils (Kellogg, 1934; Johnson et al., 1985; Munn and Boehm, 1983). In east-central North Dakota there appears to be a general relationship between landscape position and natric soils. The sodium affected soils in this part of North Dakota have been classified as Natriborolls and Natraquolls (Soil Survey Staff, 1975). The Natriborolls are further divided into glossic udic, udic, and leptic subgroups.

Extreme variability in soil properties within short distances in sodium affected soils have presented difficulties in estimating mapping unit composition. The morphologic and chemical criteria outlined in Soil Taxonomy often cannot be applied practically in the field. A case in point is the glossic udic subgroup. These soils often do not meet the requirement of an SAR of 13 or greater, yet they generally have an SAR higher than nonsodic soils. They also often lack interfingering of albic materials into the subsoil. Identificaton and delineation of sodic soils often utilizes characteristics that are not necessarily diagnostic according to Soil Taxonomy. Sodic soil taxonomic classes that emphasize soil moisture regime would remove much of the inconsistancy between classification and observed soil properties.

METHODS AND MATERIALS

The study location was in Foster County, North Dakota (Fig. 1). East-central North Dakota is in the Drift Prairie physiographic province (Feneman, 1931). Surficial geology of the study site consists of 7.5 to 15 ft of Grace City ground moraine underlain by Cretaceous Pierre Shale (Bluemle, 1965). The landscape is characterized as a closed drainage system of gentle slopes with less than 3 m relief.

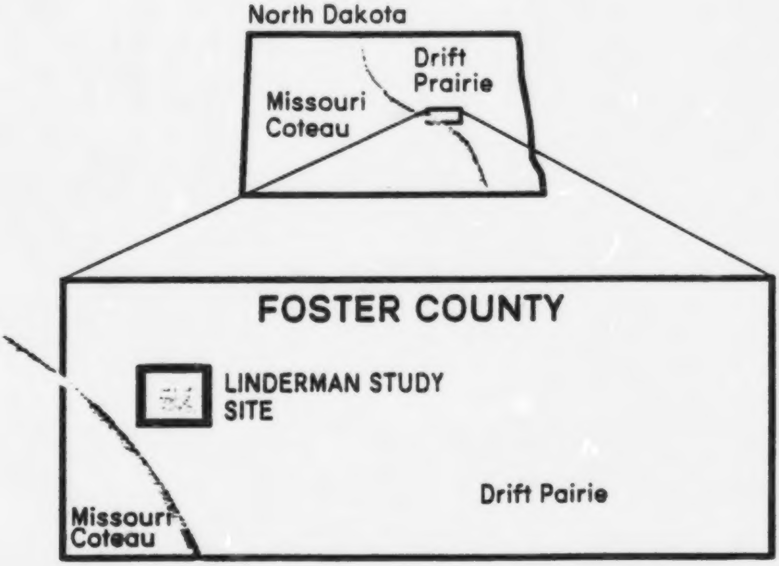

Figure 1. Natric soil study location in Foster County, North Dakota.

The climate is dry-subhumid (Thornthwaite, 1948). Average annual temperature is 4° C, with the coldest average monthly temperature in January (-14° C) and the hottest in July (21° C) (Jensen, 1972). Average annual precipitation is 422 mm, two thirds of which falls from April to August. In the summer, relative humidity averages 85% in the morning and 50% in the late afternoon.

Three landscape positions were chosen for detailed analyses of soil characteristics. They were an upland position (U), an intermediate position (I), and a wetland position (W). Initial investigations involved coring transects at three different locations in a well known area of sodium affected soils. Morphologic indicators of moisture regime, sodicity, and salinity were used to choose the landscape segment that best represented these soils. The three landscape positions represented a range of soil moisture regimes from a relatively dry upland to a wet seasonally ponded wetland. One cased well for water table observation and sampling was placed at each landscape position. Five cm inside diameter (id.) plastic pvc conduit with slits cut at 15 cm intervals was used as well casing. The well at the position (U) was 460 cm deep, at position (I) was 350 cm deep, and at position (W) was 338 cm deep. These wells were monitored monthly. Transit and stadia-board were used for a radial survey of the area. This information was used to construct 0.3 meter interval topographic map of the site (Fig. 2).

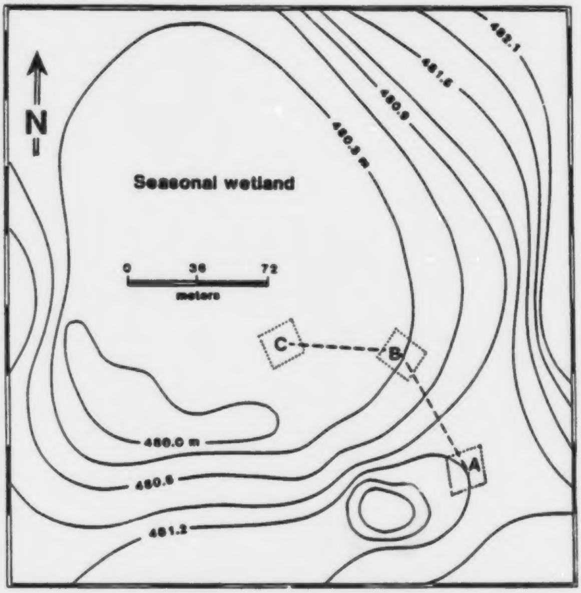

Figure 2 Topographic map of the Linderman study site (SW 1/4, NW 1/4, Sec. 27, T.146N., R.67W.) Sampling grids A, B, and C were located respectively on upland (U), intermediate (I), and wetland (W) landscape positions.

Plant communities and their composition were determined at each landscape position using a transect method. Four transects with twenty-five stops per transect were taken across each grid. Because position (I) had two different plant commmunities, two transects were taken in each community. The ten point frame was used to measure the grass composition (Levy and Madden, 1933) and a 0.1 m^2 quadrat was used to measure the composition of forbs. Relative basal cover or density and relative frequency were computed and summed to determine an importance value for each grass and forb species (Lura, 1985). The plant communities were compared to established range sites of the Drift Prairie region (Soil Conservation Service, 1975).

Each landscape position was sampled using a grid system. Pedon samples were collected at 3.0 m intervals from a 18 m by 18 m grid.

Each pedon was sampled to a depth of 150 cm using a 5 cm id. coring tube. These cores were described and classified according to the Soil Survey Manual (Soil Survey Staff, 1981), Soil Taxonomy (Soil Survey Staff, 1975), and (Canada Soil Survey Committee, 1978). Following each core description, increments of the soil horizons were separated and saved for analysis. Increments from the A, E, and B horizons were no greater than 15 cm. Increments from the C horizon were no greater than 30 cm.

One to one saturation extracts from increments of fifteen pedons from each grid were analyzed. Electrical conductivity (EC), and extractable ions were determined by standard methods used at the Soil Characterization Laboratory, NDSU. A Wheatstone conductivity bridge was employed to measure EC (Soil Salinity Staff, 1954). High correlation between total dissolved salts and extract EC is well established.. Extract Ca^{+2}, Mg^{+2}, Na^{+}, and K^{+} were determined by atomic absorbtion spectrophotometry (Chapman and Pratt, 1961). Approximately one third of the extracts were analyzed for Ca^{+2}, and Mg^{+2} using the EDTA chelation method (Heald, 1965).

Particle size (Day, 1965) and dispersible clay were determined on all increments above the B_k horizon for ten selected pedons from each grid. Organic matter was not oxidized by hydrogen peroxide prior to dispersion by either sodium hexametaphosphate or water. Dispersible clay was determined by a method used by the Salinity Lab Staff (1954) and modified by Wollenhaupt (1985). Total clay was the amount of clay in each sample as determined using the standard pipette method. Total dispersible clay was determined by pipette after soil and water had been shaken in an oscillating shaker (120 cycles/min) for 8 hr. Water dispersible clay was determined after soil and water had been gently mixed for 1 minute. Total dispersible and water dispersible clay were each divided by total clay. Two clay dispersion indices resulted: (1) percentage total dispersible clay; and (2) percentage water dispersible clay.

Data from laboratory analyses were compared to field classification of pedons. Increments from each pedon were assigned to one of four horizons: A or E; B_w or B_t; B_k; and C. Average values were then determined for the four major horizons for each pedon. An average of values from the four horizons was determined for each group of pedons in the same taxon.

Cambic and natric horizons were stratified according to landscape position. Regression analysis was employed to compare water dispersible clay to SAR and EC on the stratified data.

RESULTS

Taxonomic unit composition and soil moisture regime related to landscape position

Soils of the position (U) (Fig. 3) were dominantly moderately well drained Udic Natriborolls (Black Solonetz and Solonetzic Black Chernozems) and Udic Haploborolls (Orthic Black Chernozems) (Table 1). Typically the C horizon immediately below the B_k horizon of both these soils had a matrix color of 2.5Y 4/4 with common, fine, prominent 10YR 5/1 mottles. The water table at position (U) fluctuated from a depth of 132 cm in spring, 1987, to 262 cm in fall, 1988, (Fig. 4). The range and average of key morphologic features of these soils are shown in table (2). Natric horizons of the Udic Natriborolls displayed structure that was typically weak, medium, prismatic or columnar that parted to moderate to strong, medium to fine, subangular blocks. Cambic horizons of the Udic Haploborolls displayed structure that was typically weak to moderate, fine, prisms parting to weak to moderate, fine, subangular blocks.

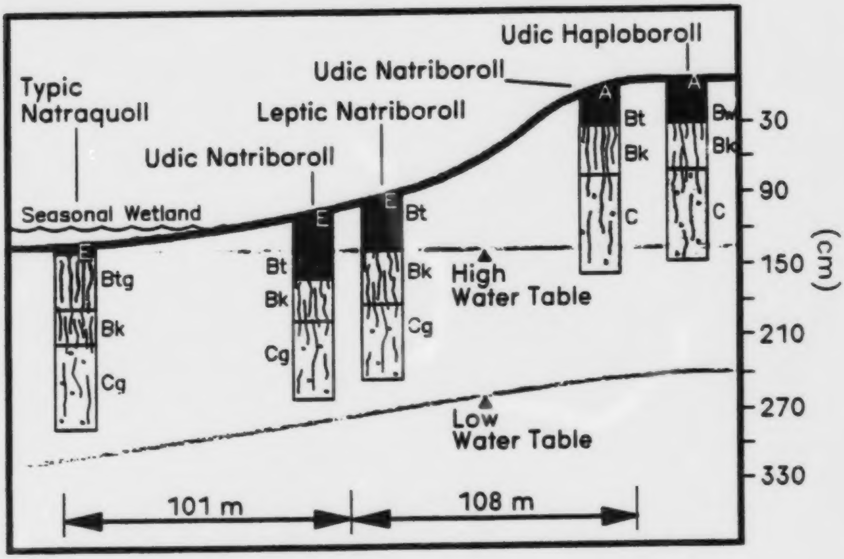
Udic Haploboroll
Udic Natriboroll
Typic Natraquoll
Leptic Natriboroll
Udic Natriboroll
Seasonal Wetland
E
Btg
Bk
Cg
E
Bt
Bk
Cg
E
Bt
Bk
Cg
A
Bt
Bk
C
A
Bw
Bk
C
High Water Table
Low Water Table
30
90
150
210
270
330
(cm)
101 m
108 m

Figure 3. Dominant soil taxonomic units of the major landscape positions at the Linderman study site. The high and low water tables occur in the spring and late winter respectively.

Table 1. Soil taxonomic unit composition of the three landscape positions at the Linderman study site.

Taxonomic Unit	Composition (%)
	UPLAND POSITION (U)
Udic Natriboroll	48
Udic Haploboroll	38
Leptic Natriboroll	12
Udic Argiboroll	2
	INTERMEDIATE POSITION (I)
Leptic Natriboroll	49
Udic Natriboroll	47
Typic Natraquoll	2
Pachic Udic Argiboroll	2
	WETLAND POSITION (W)
Typic Natraquoll	100

Soils at position (I) (Fig. 3) were dominantly somewhat poorly drained Udic Natriborolls (Black Solodized Solonetz, Black Solonetz and Black Solods) and Leptic Natriborolls (Black Solodized Solonetz and Black Solonetz) (Table 1). Forty-one of the forty-nine pedons met the mottling requirements (usually 2.5Y 4/2 or 5Y 4/2 matrix with high chroma mottles within 75 cm of the surface) for Typic Natraquolls. However, it was questionable whether soils at this position were saturated to the surface for long enough periods to be considered Aquolls. Both Leptic and Udic Natriborolls of position (I) also had colors in the substratum that suggested a wetter moisture regime than that of the soils of position (U). The matrix color in the substratum was typically mottled 5Y 4/3 and 5Y 5/1. The water table at position (I) fluctuated from a depth of 40 cm in the spring, 1987, to 208 cm fall, 1988, (Fig. 4). Averages and ranges of key morphologic features for these soils are shown in Table (2). The upper part of the natric horizon for both of these soils typically had moderate to strong, medium to coarse, columns or prisms parting to weak or moderate, fine, subangular blocks. The lower part had weak to moderate, fine, prisms parting to weak or moderate, fine, subangular blocks. All pedons had a very light textured E horizon (ususally silt loam) with platy structure that, when dried became noticeably lighter in color than the underlying natric horizon. Also some Udic Natriborolls had a light colored (10YR 4/2) E horizon that met the albic requirements. Many of the profiles had a B/E horizon that had bleached sand and silt grains extending into the B_t horizon on the surfaces of the columns or prisms. Leptic Natriborolls had salt crystals, on average, within 12 cm of the surface and ranged from 5 to 30 cm.

The soils of position (I) occured in a regular pattern with respect to each other. Leptic Natriborolls were concentrated on the more elevated upslope portion of the landscape position. Udic Natriborolls occupied the downslope portion and seemed to serve as a transition to the wetter soils of position (W).

The dominant soils at position (W) (Fig. 3) were poorly drained Typic Natraquolls (Gleyed Black Solonetz, Gleyed Black Solodized Solonetz and Gleyed Black Solods) (Table 1). Key morphologic features that differentiated most of the soil profiles of position (W) from those of position (I) were the colors and mottles in the B/E horizon and the upper part of the B_t horizon. Typic Natraquolls typically had 5Y hue colors with prominent high chroma mottles in these horizons. The hue of colors in corresponding horizons of Natriborolls of grid B was usually 10YR and only rarely were high chroma mottles present. The water table at position (W) flucuated from a depth of 10 cm in spring, 1987, to 227 cm in fall, 1988, (Fig. 4). An element of the moisture regime that was not evident from observation of water table depths was ponding in the spring. Position (U) had no observed ponding, and position (I) had very limited ponding in the micro-depressions for short periods. However, extensive ponding occured at position (W), from February through April in 1987. The upper part of the natric horizon typically had moderate to strong, medium to coarse, prisms and columns parting to weak or moderate, fine, subangular blocks. The lower part had weak to moderate, fine to medium, prisms parting to weak or moderate, fine, subangular blocks. Similar to the soils at position (I), all

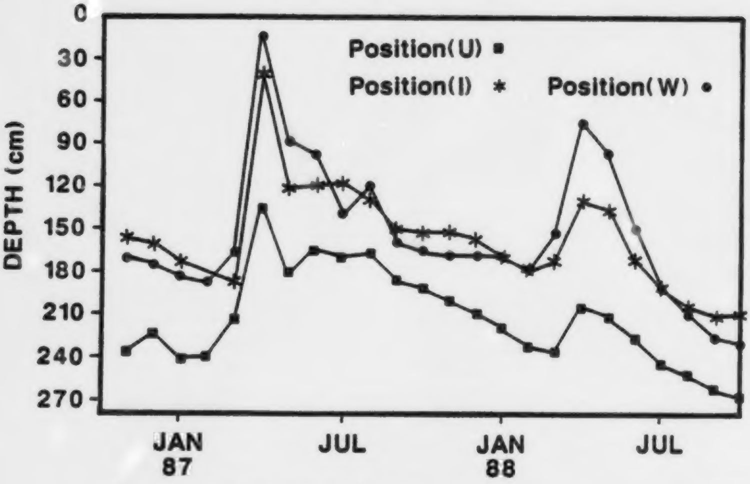

Figure 4. Well hydrographs from the major landscape positions at the Linderman study site. Data was collected monthly from November 1986 to October 1988.

Table 2. Morphologic characteristics of dominant taxonomic units at the Linderman study site (Average/Range)

Classification	Depth to salt (cm)	Depth to k horizon (cm)	Mollic epipedon	Surface horizon	Bw or Bt horizon
			.....thickness (cm).....		
			POSITION (U)		
Udic Natriborolls	--	27	27	10	15
	60->150	15-40	15-45	5-22	5-30
Udic Haploborolls	--	27	27	15	10
	18->150	18-35	18-38	5-20	0-22
			POSITION (I)		
Udic Natriborolls	135	65	48	12	38
	55->150	30->150	12-78	2-30	12-65
Leptic Natriborolls	12	42	40	2	40
	2-30	27-72	27-72	0-12	20-72
			POSITION (W)		
Typic Natraquolls	118	55	38	12	40
	15->150	20->150	15-62	5-22	18-82

Typic Natraquolls had an E horizon with platy structure and light texture (usually silt loam) that upon drying became considerably lighter in color than the upper part of the natric horizon. Some of these profiles also had E horizons with colors from 10YR 4/2 to 5/2 that met the requirements of an albic horizon. The E horizon often extended into the B_t horizon as evidenced by many profiles with a B/E horizon. Salt crystals were found near the surface in some soil profiles.

Chemical and physical data for taxonomic units

Chemical and physical analyses of pedons from each landscape position generally supported taxonomic placement of the soils. The average B_t/E ratio of clay percentages was greater than 1.2 for all natric taxonomic units. Even the average B_w/A ratio of clay percentages of the Udic Haploborolls was greater than 1.2. Although results of the particle size analysis did not always agree with the field estimates of clay, they did verify that the B_t/E ratios met the clay criteria for a natric horizon. Obvious differences in dispersible clay between B horizons of these soils can be seen (Fig. 5). Mechanical agitation dispersed approximately 30% to 40% of the total clay. The effect of mechanical agitation seemed to be similar for all soil taxonomic units. Figures (6, 7, 8) show the chemical relationships between the cambic or natric horizons of the dominent soils on this landscape. In general the pattern of SAR closely resembles that of water dispersible clay (WDC). The pattern of EC parallels the observation of salt crystals. The Ca/Mg ratio has a pattern that is inversely related to the WDC.

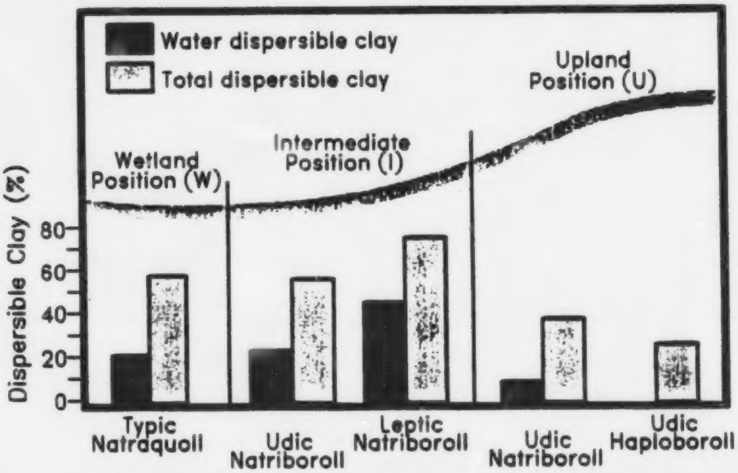

Figure 5. Average percentages of total dispersible clay (TDC) and water dispersible clay (WDC) in the cambic or natric horizon of the dominant taxonomic units.

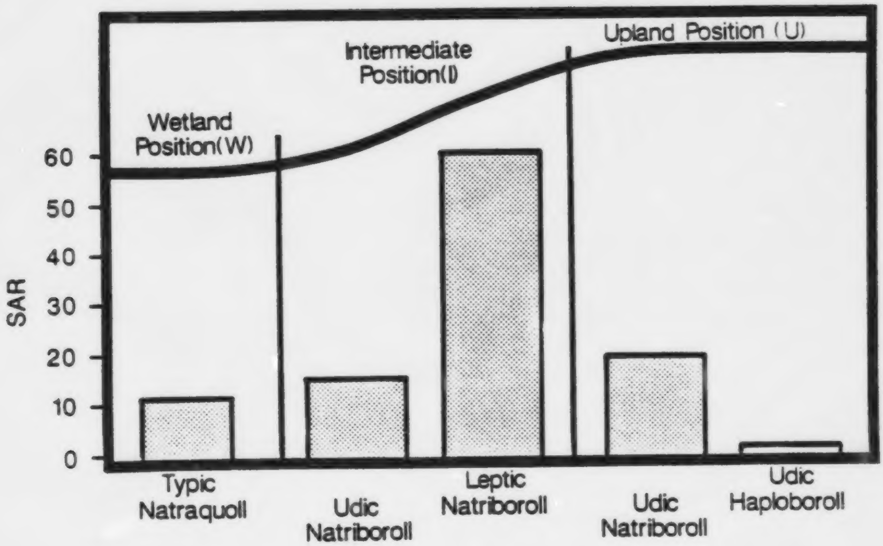

Figure 6. Average 1:1 saturation extract sodium adsorption ratio (SAR) in the cambic or natric horizon of the dominant taxonomic units.

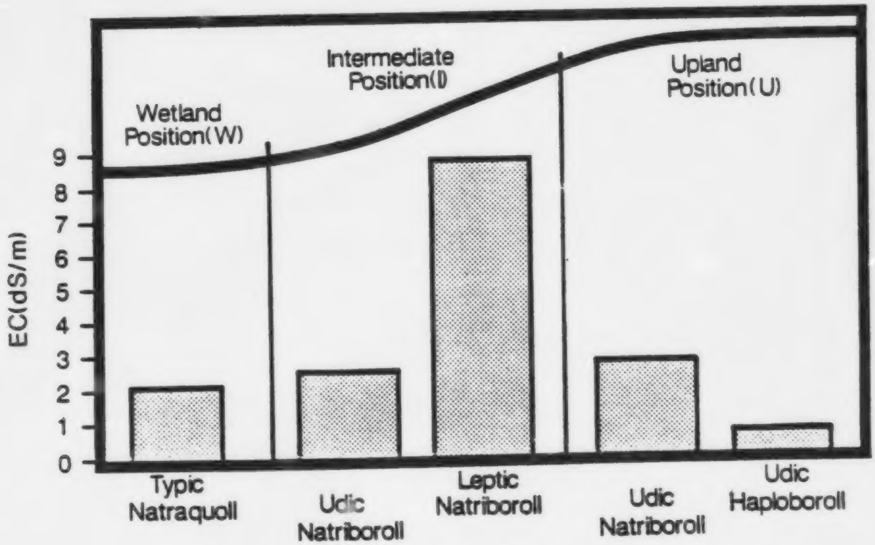

Figure 7. Average 1:1 saturation extract electrical conductivity (EC) in the cambic or natric horizon of the dominant taxonomic units.

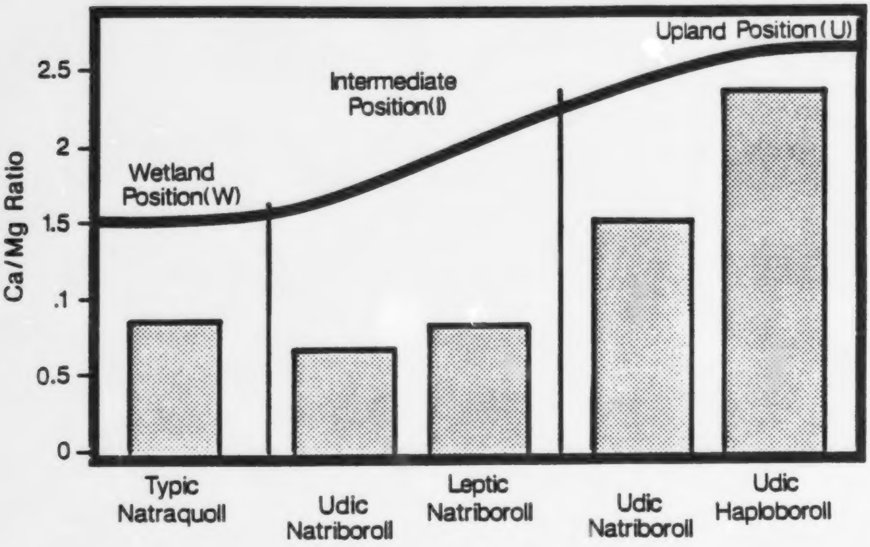

Figure 8. Average 1:1 saturation extract Ca/Mg ratio in the cambic or natric horizon of the dominant taxonomic units.

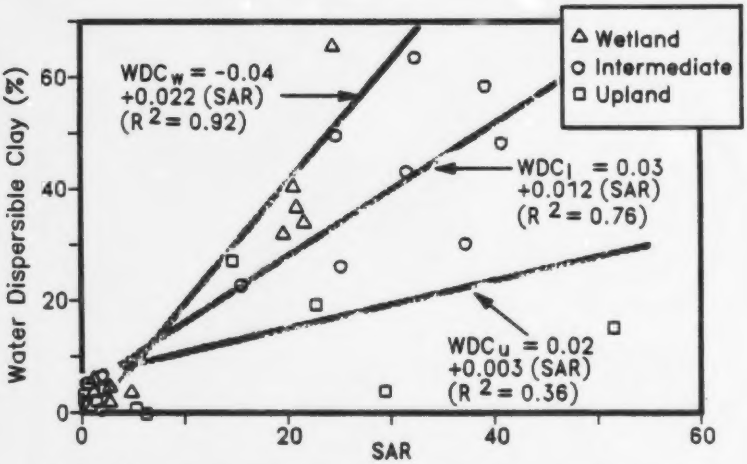

Figure 9. Scattergram and regression lines of water dispersible clay (WDC) versus sodium adsorption ratio (SAR) of the cambic or natric horizons of the dominant taxonomic units stratified by landscape position.

Table 3. Regression equations for water dispersible clay (WDC) versus sodium adsorption ratio (SAR) and electrical conductivity (EC).

Dependent Variable	Independent Variable(s)	Regression Equation	Coefficient of determination (R2)
		UPLAND POSITON (U)	
WDC	SAR	$WDC=0.02+0.003(SAR)$	0.36
WDC	SAR, EC	$WDC=0.03+0.01(SAR)-0.048(EC)$	0.60
		INTERMEDIATE POSITION (I)	
WDC	SAR	$WDC=0.03+0.012(SAR)$	0.76
WDC	SAR, EC	$WDC=0.01+0.02(SAR)-.032(EC)$	0.83
		WETLAND POSITION (W)	
WDC	SAR	$WDC=-0.04+0.022(SAR)$	0.92
WDC	SAR, EC	$WDC=-0.04+0.026(SAR)-O.02(EC)$	0.93

Results of the regression on the stratified data of water dispersible clay, SAR, and EC, from the cambic and natric horizons showed an interesting pattern. Figure (9) indicates that SAR accounts for much of the variation in WDC at positions (I) and (W). However, it is not very effective in predicting WDC at position (U). Table (3) shows improvement of the coefficient of determination at all three positions when EC is added to the regressions. Inspite of this improvement, much of the variation in WDC at position (U) remains unexplained.

Plant communities related to landscape position

Vegetation transects revealed four distinct plant communities on this sodium affected landscape (Fig. 10). All of these plant communities were dominated by grass or sedge species. The dominant grass at position (U) was *Poa pratensis* (Kentucky bluegrass). The dominant forb at this position was *Euphorbia glyptosperma* (ridge-seeded spurge). Position (I) had two plant communities. The first community was dominated by *Distichlis stricta* (inland saltgrass) and Kentucky bluegrass. The second community was dominated by Kentucky bluegrass; *Agrostis hiemalis* (tickle grass); and *Carex lanuginosa* (wooly sedge). *Artemisia ludoviciana* (white sage) was the dominant forb in both of these plant communities. The inland saltgrass - Kentucky bluegrass plant community coincided with the area of Leptic Natriborolls at position (I). The Kentucky bluegrass - tickle grass - wooly sedge plant community coincided with the area of Udic Natriborolls. The boundaries between these two plant communities and the two soils were remarkably similar. Dominant species at position (W) were *Hordeum jubatum* (wild barley); *Calamagrostis stricta* (northern reedgrass);

and wooly sedge. There were so few forbs at this position, that no transects for their identification were taken.

DISCUSSION

The landscape positions studied have discernable differences in their soil properties. We are presenting a general model that relates natric soil properties to landscape.

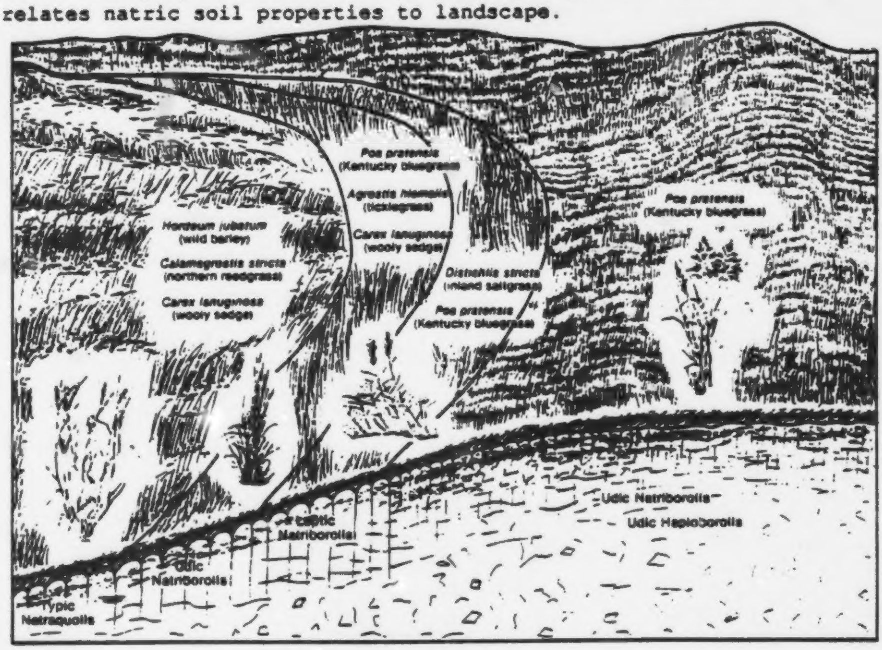
Poa pratensis
(Kentucky bluegrass)
Agrostis hiemalis
(ticklegrass)
Carex lanuginosa
(wooly sedge)
Hordeum jubatum
(wild barley)
Calamagrostis stricta
(northern reedgrass)
Carex lanuginosa
(wooly sedge)
Distichlis stricta
(inland saltgrass)
Poa pratensis
(Kentucky bluegrass)
Poa pratensis
(Kentucky bluegrass)
Udic Natriborolls
Udic Haploborolls
Leptic Natriborolls
Udic Natriborolls
Typic Natraquolls

Figure 10. A view of the plant communities at the Linderman study site and their relationship to the soils and landscape.

Interrelationships between soils, moisture regime, and plant community of the upland landscape position

The upland landscape position (U) was dominated by Udic Natriborolls and Udic Haploborolls. These taxonomic units had the driest moisture regime on this landscape as indicated by soil morphology and confirmed by water table data. The soils of this position would be placed in the silty or claypan range sites. Position (U) lacked much diversification in its plant community. When these sites are grazed dominance of Kentucky bluegrass is a likely result. Clay dispersion indices indicated these two taxonomic units were the least affected by sodium. Morphology of the B_w horizon for Udic Haploborolls and the B_t horizon for Udic Natriborolls also lead to this conclusion. Low average SAR in the cambic horizon of the Udic Haploborolls provide chemical confirmation.

Udic Natriborolls from position (U) exhibited morphology in the B_t horizon that was intermediate between soils unaffected by sodium (Udic Haploborolls) and more severely affected taxonomic units further downslope. Clay dispersion indices for these soils were considerably lower than for other sodium affected taxonomic units, thus verifying conclusions based on observation of soil morphology. In spite of the low amount of dispersible clay, average SAR for the natric horizon reveals Udic Natriborolls from position (U) to be comparable to natric horizons of Udic Natriborolls from position (I) and Typic Natraquolls. The explanation for this apparent inconsistency between the chemical and physical data may be related to the relative occurrence of calcium and magnesium in the cambic or natric horizons of the soils on this landscape.

Based on regression analyses of SAR versus water dispersible clay (WDC) from the cambic or natric horizons, we suggest that sodium is the primary factor responsible for clay dispersion at all landscape positions. Because regression analyses were run on stratified data, it is possible to postulate on the effectivness of sodium in dispersing clay in soils at each landscape position. In the natric or cambic horizons of soils at position (U), sodium was least effective in dispersing clay, where average Ca/Mg ratios were greater than 1. Sodium plays a much more effective role in the dispersion of clay in the natric horizon of soils from positions (I) and (W), where the average Ca/Mg ratios are less than 1. The ancillary effect of magnesium on the ability of sodium to disperse soil clays has been demonstrated by Paliwal and Gandhi (1976) and Alperovitch, et al (1981). This effect would be expected to be minimal in soil horizons with large Ca/Mg ratios as observed in the Udic Natriborolls of position (U).

Interrelationships between soils, moisture regime, and plant communities of the intermediate landscape position

Both Leptic and Udic Natriborolls, the dominant taxonomic units at position (I), had wetter moisture regimes than the soils at position (U). A higher seasonal water table at position (I) helps explain the dominance of 5Y hues in the substra of the soils. Morphology of the Leptic and Udic Natriborolls from position (I) also indicated soil conditions with greater potential for clay dispersion than at position (U). Average WDC of the natric horizons was much higher than for soils from position (U). An extremely high average SAR for the natric horizon of the Leptic Natriborolls correlated well with the morphology and WDC of these soils. Sodium is quite effective in dispersing clay in the natric horizon of Udic Natriborolls from position (I). As discussed earlier, a relatively low Ca/Mg ratio in the natric horizon may be one of the reasons for this observation. Average EC of the natric horizons of Leptic Natriborolls was very high. Thus, observation of salt crystals within 40 cm of the surface was a reasonable estimate of high salinity. In spite of high EC in the Leptic Natriborolls, clays remained highly dispersible, because the SAR was overwhelmingly high.

At position (I) soils and plant communities occured in two distinct zones. Natriborolls occured as zones around Typic Natraquolls of position (W). Leptic Natriborolls were the higher outside zone and Udic Natriborolls the lower inside zone. Leptic Natriborolls would be best placed in the thin claypan range site. Codominant inland saltgrass and Kentucky bluegrass are likely to occur under grazing. Udic Natriborolls at position (I) do not fit well into any single range site. The dominance of Kentucky bluegrass, tickle grass, and wooly sedge would be expected on a grazed pasture with some characteristics of all three of the claypan, wetmeadow, and subirrigated range sites. Recognition of soil and vegetation patterns such as these, is essential to accurate identification and delineation of soil properties on this landscape.

Interrelationships between soils, moisture regime, and plant community of the wetland landscape position

The dominant taxonomic unit at position (W) was poorly drained and frequently ponded Typic Natraquolls. Average EC, SAR, Ca/Mg ratio, and WDC of the natric horizons of Typic Natraquolls were very similar to that of Udic Natriborolls of position (I). Therefore, justification for separating these two taxonomic units must depend on a discernible difference in soil moisture regimes. The slight difference in seasonal water table depths between their respective landscape positions did not provide enough evidence. However, other indicators of water regime did suggest that the taxonomic unit at position (W) was wetter. Extensive ponding was observed to occur only at position (W). Dominance of 5Y hues, with common high chroma mottles, in the lower part of the mollic epipedon of Typic Natraquolls at position (W) also indicated a much wetter moisture regime. These colors and mottles were rarely observed in profiles of Udic Natriborolls of position (I). The plant community at position (W) was dominated by wild barley, northern reedgrass, and wooly sedge. These species would be expected under grazing of wet meadow or saline lowland range sites with poorly drained soils. The composite weight of all of these indicators provides the justification for separating Typic Natraquolls of position (W) from Udic Natriborolls of position (I). Without the ponding effect, soils of position (W) probably would not be saturated in the surface horizons long enough to meet the criteria for an aquic moisture regime at the suborder level.

The influence of moisture regime on soil properties as determined by landscape position

Landscape position by itself probably has little direct effect on the distribution of SAR, EC, Ca/Mg ratio, and WDC ; however, the indirect effect is through control of the soil moisture regime. In addition to soil solution and exchange complex chemistry, mechanical effects of wetting and drying are important to clay dispersion (Rengasamy, et al, 1984). Therefore, water content fluctuations, must play a significant role in the determination of amount and distribution of dispersible clay in the soil profile. In effect, stratification of the data by landscape position is a method of introducing moisture regime into the model for explaining dispersible clay. The three different relationships between SAR, EC, and WDC generated by stratifying the data by landscape position point out the obvious influence of soil moisture regime. They provide justification for using soil moisture regime as a major taxonomic criteria for the natric soils in this area. Results of regression analyses infer, that fundamental differences in the relationship between physical properties and chemical properties occur among natric soils of different landscape positions. In order to understand, classify, and manage these soils; recognition of these differences is imperative.

CONCLUSIONS

1. Landscape position is an excellant predictor of natric soil properties. Upland landscape positions are dominated by moderately well drained Udic Natriborolls and Udic Haploborolls. Intermediate positions are dominated by somewhat poorly drained Udic Natriborolls and Leptic Natriborolls. Depressional positions are dominated by poorly drained Typic Natraquolls. Regression analysis of cambic and natric horizon WDC versus SAR and EC verifies that landscape position and soil moisture regime must be recognized to properly understand and manage these soils.

2. Morphologic evidence of observable differences between the above soil taxonomic units is supported by substantial differences in physical and chemical properties, watertable levels, and plant communities.

3. Our data indicate that natric soils in the depressional positions are poorly drained due to temporary ponding in the spring and early summer. Aquic moisture regime color and mottling criteria should be tailored to the soils on these landscapes. This will allow consistent separation of somewhat poorly drained soils from poorly drained soils or ponded soils.

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Distribution of soils on an alluvial fan at the Hettinger Experiment Station, North Dakota

D.G. Hopkins and M.D. Sweeney

Department of Soil Science, North Dakota State University

INTRODUCTION

A detailed soil survey of agricultural experiment station lands is a fundamental tool for the interpretation of agronomic research. Agronomists need to be aware of edaphic variation in plot areas in order to correctly evaluate the response of specific plant materials to applied treatments.

An intensive soil survey was initiated on the Hettinger Experiment Station in southwestern North Dakota with a primary goal of locating a new soil area for small grain variety trials. Previous locations proved unsuitable due to extremely droughty conditions when plots were located on an abandoned river terrace and subsequent problems with salinity, sodicity, and crusting when plots were moved to a lower terrace position (J. Jakicic, personal communication, 1987). A 108 ha area was selected for further study because it appeared to be the most uniform and suitable area for the variety trials.

The objectives of this study were to:

1) relate soil morphology to topographic variation
2) assess soil salinity using an electromagnetic induction meter
3) assess soil crusting potential in the A horizon using modulus of rupture.

METHODS AND MATERIALS

The study area is located in the eastern half of Sec. 11, T129N, R96W. The parent material is alluvium derived from medium-textured sediments of the Slope and Bullion Creek Formations (Paleocene). The soils are classified as the Shambo series, Orthic Dark Brown (Canadian), fine-loamy, mixed Typic Haploborolls (U.S.), and the Belfield series, Dark Brown Solod (Canadian), fine, montmorillonitic, Glossic Natriborolls (U.S.) (Soil Survey Staff, 1975; The Canadian System of Soil Classification, 1987).

A topographic map was made of the study area based on 9.2 m observation intervals using a surveyors' level (Fig. 1). A salinity survey was made on 18.4 m intervals using a Geonics EM-38 electromagnetic induction meter*. Soil electrical conductivity (1:1 soil water extract) was obtained from 18 pedons sampled in 0.3 m increments to 1.2 m for comparison with induction meter readings. Soil electrical conductivity (EC) was determined on 1:1 soil/water suspensions (Dahnke, 1980).

Four transects were established radially from the common point of highest elevation in the study area (Fig. 1). Each transect had 11 or 12 pedon description sites. Soils were described to 1.2 m depth using procedures of the National Cooperative Soil Survey (Soil Survey Staff, 1951). Fifteen soil profiles were examined in areas of concave microrelief to supplement the transect observations which were largely on convex landscape positions. Morphologic properties noted were solum horizonation and structure, depth to the Bk horizon, depth to soluble salts (principally gypsum) and presence of textural discontinuities at depth in the profile.

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* The use of trade names does not imply the endorsement of the North Dakota Agricultural Experiment Station for the products named or criticism of similar ones not mentioned.

A Belfield and Shambo soil were selected for detailed laboratory characterization as a result of preliminary investigations in the study area. Soluble salts were determined on saturated paste soil extracts using the methods of Rhoades (1982). Calcium, magnesium, and sodium, (Ca, Mg, and Na) were determined with atomic adsorbtion spectroscopy using methods of Chapman and Pratt (1961). Adjusted sodium adsorbtion ratio (SAR_{adj}) was calculated using concentrations of Ca, Mg, and Na corrected for ion pairs and activities (Alzubaidi and Webster, 1983). Exchangeable cations were determined using $BaCl_2$-TEA as described by Thomas (1982). Particle size analysis was determined by pipette method (Day, 1965).

Crusting potential was estimated with modulus of rupture using a modification based on the method of Reeve (1965). Samples were obtained from the A horizon on 28 m intervals, dried, and ground to pass a 2 mm seive. Data reported are the average of 4 replications.

RESULTS AND DISCUSSION

The study area is located on an alluvial fan which is dissected by a small drainage in the southeast quarter and bordered by depressions on the north and west. The topographic map based on 0.3 m contour intervals illustrates the surface expression of an alluvial fan landform (Fig. 1). The slope is 1.3 % from the apex to the lowest elevation on the fan. Microrelief is convex across most of the study area except for a distinct zone near the apex of the fan and in depressions previously mentioned.

Results of the induction meter survey indicate that the study area is generally nonsaline, though several zones of higher soil salinity (above 0.75 dS/m) are distributed on the alluvial fan (Fig. 1). Two trends are apparent from the distribution of saline areas. Not all depressional areas have low salinity levels but the two most extensive zones (in the west central portion of the study area) appear controlled by topography as shown by their relationship to contour lines.

Salinity profiles of the soils sampled for 1:1 soil EC indicate that higher EC is found below 0.6 or 0.9 m in nearly all the soils analyzed. Soil EC is less than 0.5 dS/m above 0.6 m depth. Twenty two percent of the pedons studied had EC levels above 1.0 dS/m in the 0.6-0.9 m depth increment while the remaining pedons had values considerably lower than 1.0 dS/m. The zones of higher salinity were nonsaline above 0.6 m depth and ranged from approximately 2.0 to 11.0 dS/m in the 0.6 to 1.2 m depth increments.

Inspection of the 58 profiles studied for morphologic variation suggests that the primary differentiating properties are best explained by microtopographic position. Soils on concave landscape positions are leached more than soils on convex positions even though the overall gradient is very low. Concave microrelief results in Bk horizons being markedly deeper than in soils with a convex surfaces (Fig. 2). The subsurface continuity of gypsum enriched horizons (By horizons) is interrupted by greater leaching below concave surfaces (Fig. 2). It is interesting to note that the only profile expressing eluvial morphology (A/E horizon) was observed below the most concave landscape position (Fig. 2).

The soils examined can be stratified into two classes, those above and below the 50 cm midpoint of the range observed in depth to carbonates. Where the surface of the fan is uniformly convex the soils have developed Bk horizons at a depth of about 38 cm, but where the surface position is concave, Bk horizons are found at depths of about 63 cm. Identifying the location of members of the less deeply leached class on the alluvial fan reveals the importance of microtopographic position (Fig. 3). Most convex areas have soils with Bk horizons that are within 50 cm of the surface.

Soils developed on convex microtopographic positions on the alluvial fan have only weakly developed cambic B horizons (Bw horizons) above the Bk horizon. Soil profiles expressing strongly eluviated E horizons and illuvial Bt horizons were found clustered at the end of a transect in the southwest quarter of the study area or in areas of concave microrelief.

Soil physical and chemical data from the Shambo and Belfield characterization profiles provide additional evidence for different genetic pathways for the two soils. The Shambo soil developed in relatively uniform sediments but variation in the sand fraction suggests that the materials are stratified (Table 1). Markedly higher fine clay percentages in the upper half of the Shambo profile indicate two distinct depositional episodes (Daniels et al., 1971).

Alternating periods of stability and sedimentation on the alluvial fan are shown by the recognition of a 2Bwb horizon in the Shambo characterization profile. This horizon had 10YR 4/3 dry colors, contrasting the Ap horizon which was much lighter (10YR 6/2). The thickness and lateral continuity of the 2Bwb horizon suggest that it is in fact a pedogenic horizon, and not an artifact or krotovina. A relatively thick buried A horizon which was darker than the present surface was observed in a transect site located southeast of the Shambo profile. This Ab horizon was at 107-122 cm depth and could logically have been the surface associated with the 2Bwb horizon of the Shambo profile found at 119-152 cm depth. Both of these profiles are on the uniformly convex surface of the alluvial fan.

Fine clay percentages strongly indicate a depositional interval and pedogenic hiatus in the Shambo profile, yet the fine clay bulge in the Belfield illuvial horizon sequence is evidence of pedogenic stability (Table 1) (Whittig, 1959). The Bt horizon in the Belfield soil is also the highest in total clay percentage (Table 1).

The fine clay bulge and high total clay percentages in the Belfield illuvial horizons suggests strong translocation processes, yet only thin continuous clay skins were observed on ped faces. The presence of thin clay skins suggests that the processes of clay translocation are not as intense as they once were; the Belfield profile may be very old. The fact that the lower Bt horizon in the Belfield profile is calcareous is additional evidence for the substantial age of the Belfield soil because clay translocation processes will not occur in a calcareous soil (Soil Survey Staff, 1975).

Presence of $CaCO_3$ in the Btk horizon suggests that the Belfield soil is in contact with carbonate-charged groundwater. This hypothesis is supported by the salinity profile of the Belfield soil. Increasing salinity at the soil surface is the pedogenic signature of capillary rise of saline groundwater.

Coarse textured substratum (loamy fine sands and fine sandy loams) were found at depths below one meter in 11 of the 58 pedons observed. It is very likely that these strata act as conduits for throughflow of saline and sodic groundwater. The sandy lenses may explain the apparently random distribution of saline areas on the alluvial fan and have been an integral factor in genesis of the Belfield soils.

The eluvial/illuvial morphology, very low adjusted sodium adsorbtion ratio (SARadj), and high calcium/magnesium ratio in the upper solum of the Belfield soil are consistent with the concept of the "solod" profile (Kovda, 1939). The source for the sodium that was initially present in the Belfield soil is very likely found in the highy saline and sodic Shambo substatum (Table 1). The current salinity profile of the Belfield soil reflects groundwater discharge and is evidence of the polygenetic nature of the Belfield soil; discharge processes are incompatible with solod morphology and chemistry.

Surface crusting potential is variable on the alluvial fan but appears greatest in areas of concave microrelief (Fig. 4). The highest values obtained in the modulus of rupture analysis were observed in both Belfield soil areas and in the area of high salinity located in the west central part of the study area (Fig. 4).

Given that the silt and clay percentages are very similar for Shambo and Belfield soils (Table 1), the cause of variation in crusting potential is likely due to differences in soil chemistry. Values for SAR_{adj} are very low for both Belfield and Shambo soils indicating that sodium saturation per se may not contributing to high crusting potential. There is a possibility that higher magnesium concentrations in the Belfield Ap horizon influence soil physical properties (Table 1). Modulus of rupture results from mixed cation soil samples showed that the Mg-Na saturated systems had markedly poorer soil physical properties than comparable Ca-Na systems (Van der Merwe and Burger, 1969).

An alternate hypothesis for poor physical condition in the Belfield soil areas may be due to pedogenic attributes of the solod soil. It is well established that as solodization proceeds, hydrolytic breakdown of clay minerals occurs releasing silicic acid. Lewis and White (1964) have proposed that amorphous silicate gels contribute to the impermeability of solonetzic B horizons. Occasional flooding on the surface of degraded alkali soils (Solod) has been suggested as a cause of high levels of amporphous silica. Anaerobic microbial sulfide production and subsequent release of sulfuric acid upon return to areobic conditions could attact silicates and release silica (McKeague and Cline, 1963). Silica is likely higher in Belfied than Shambo soils and could contribute to the higher crusting potential observed in modulus of rupture analysis. Additional work is required to determine why Belfield soils have higher crusting potential on the alluvial fan.

CONCLUSIONS

The variation and distribution of soil morphologic, chemical, and physical properties as discussed above emphasizes the fundamental need for agronomists to account for edaphic variability when interpreting experimental results.

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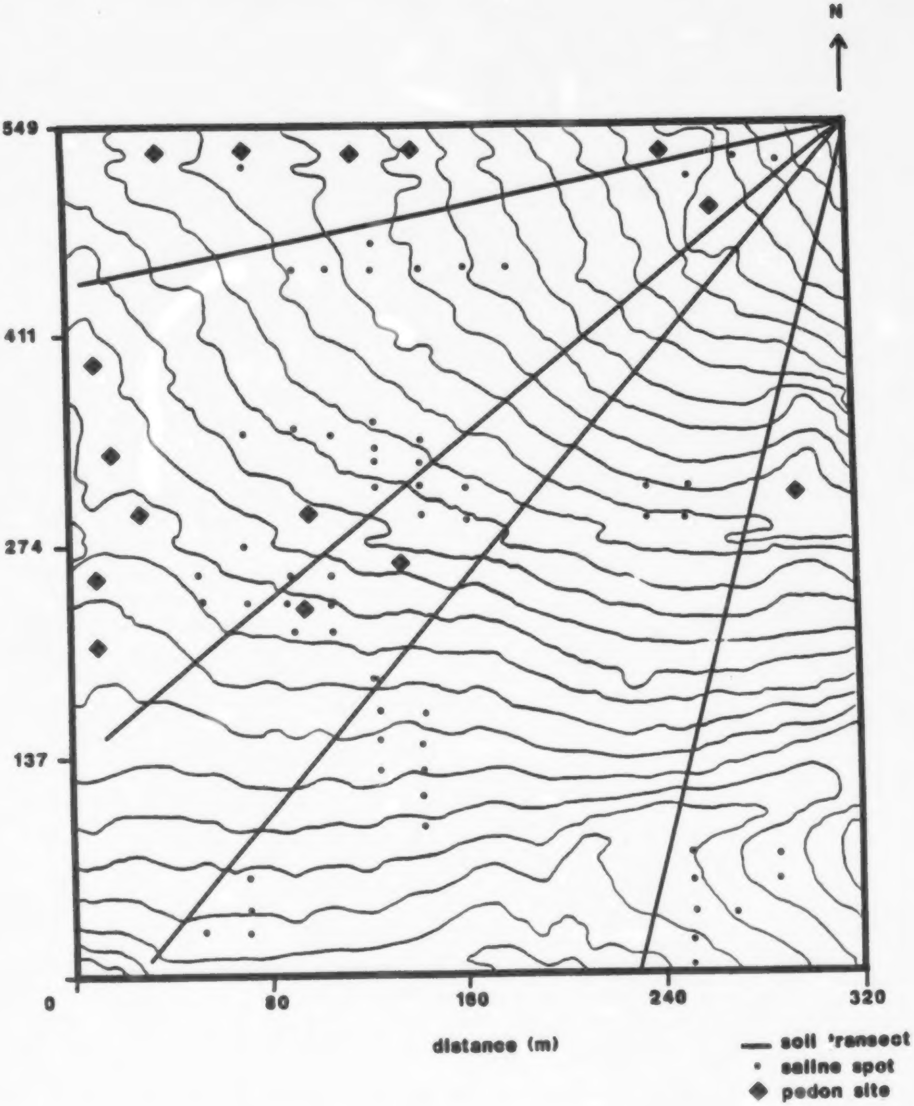
N
549
411
274
137
0
80
160
240
320
distance (m)
— soil transect
• saline spot
◆ pedon site

Figure 1. Hettinger Experiment Station study area showing topography on 0.3 m contour intervals. Soil transects, areas of high salinity, and supplemental pedon sites are defined in legend.

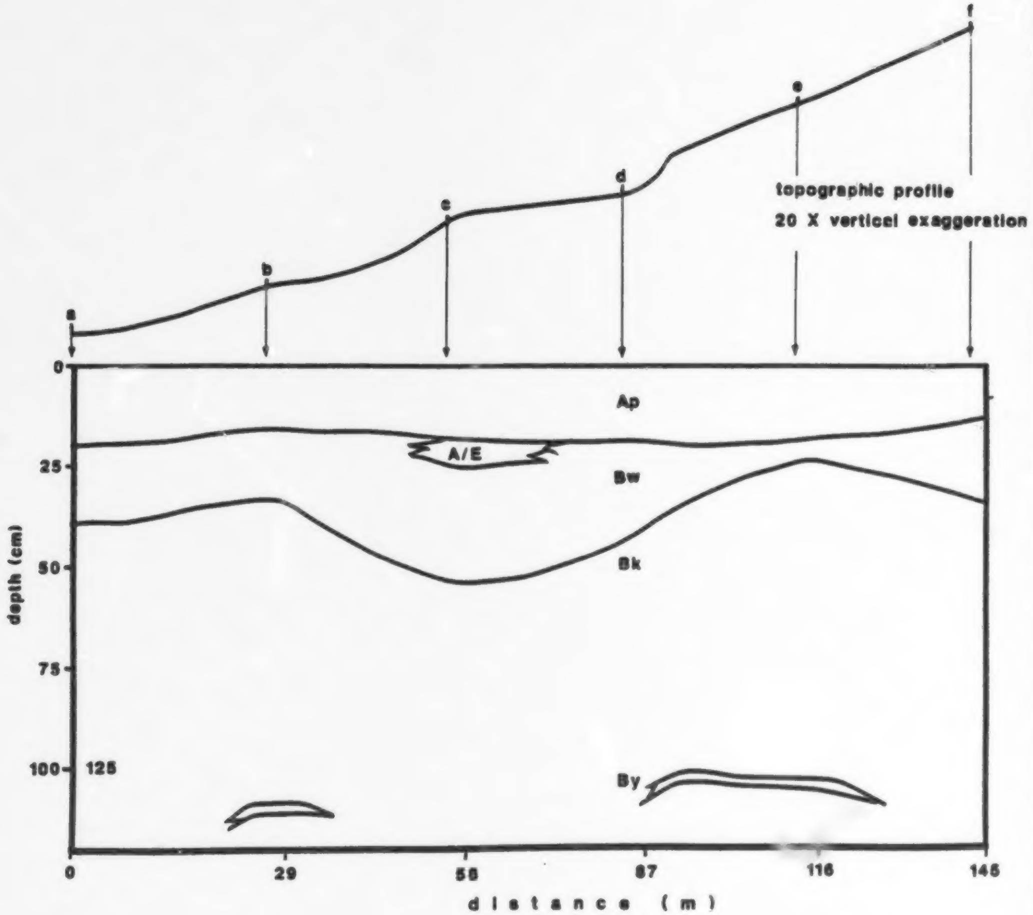
a
b
c
d
e
f
topographic profile
20 X vertical exaggeration
Ap
A/E
Bw
Bk
By
125
depth (cm)
0
25
50
75
100
0
29
58
87
116
145
distance (m)

Figure 2. Topographic surface profile and soil morphology illustrating differential leaching. Horizontal section is of the eastern third of the north soil sampling transect.

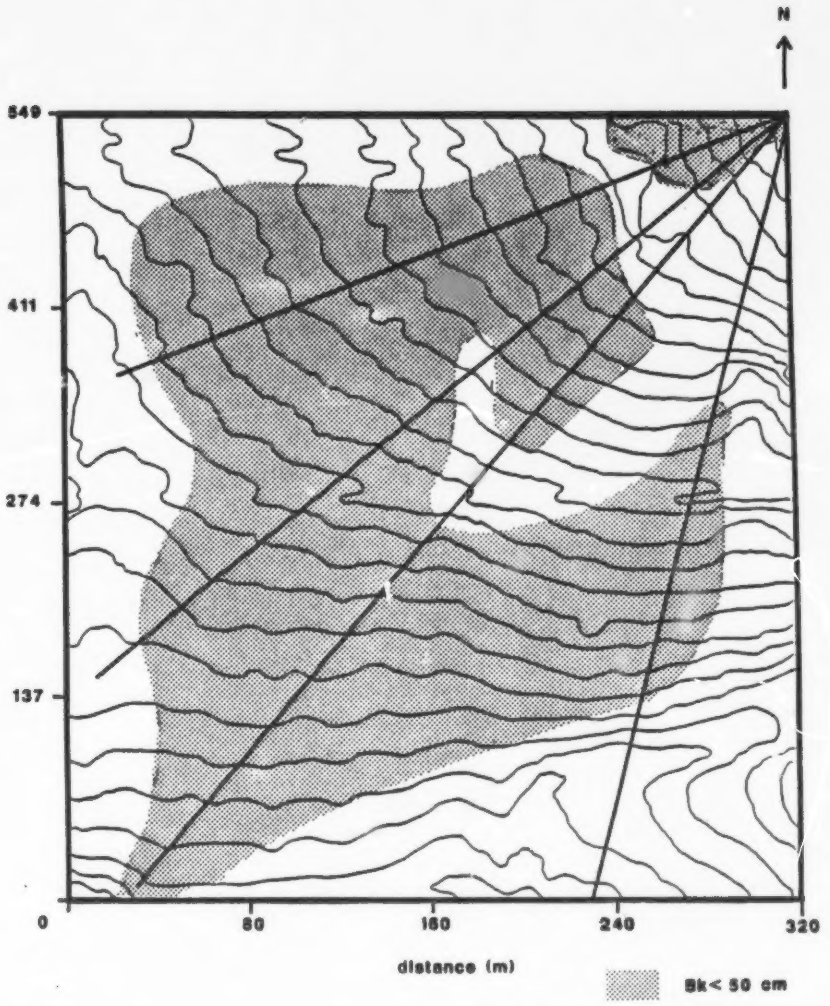
N
549
411
274
137
0
80
160
240
320
distance (m)
Bk< 50 cm

Figure 3. Generalized distribution of soils having Bk horizons within 50 cm of the soil surface.

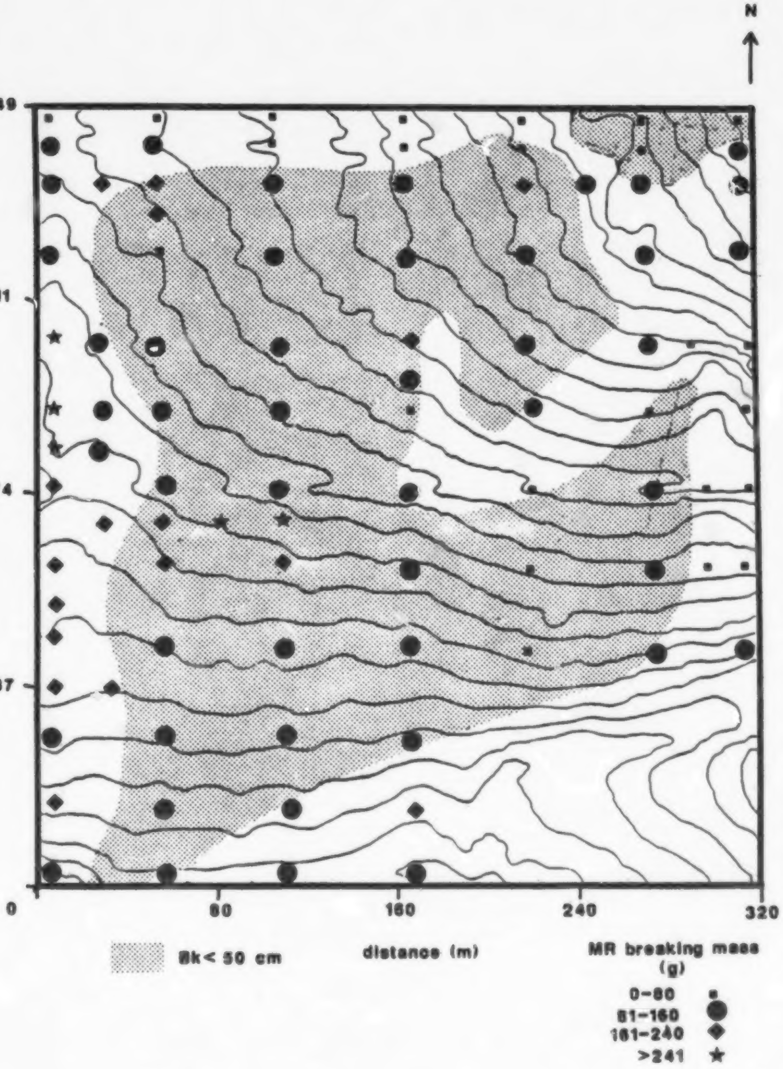
N
549
411
274
137
0
80
160
240
320
Bk< 50 cm
distance (m)
MR breaking mass
(g)
0-80
81-160
161-240
>241

Figure 4. Distribution of modulus of rupture (MR) results in relation to soils having Bk horizons within 50 cm of the soil surface. Mass obtained at soil fracture shown in legend.

Table 1. Selected morphologic, physical, and chemical soil properties of the major soils of the study area.

Horizon	Depth cm	Textural Class	--Particle Size Analysis--				EC dS/m	SAR Adj	Ca/Mg* Ratio
			Sand	Silt	Clay	Fine Clay			
			----------%----------						
Shambo									
Ap	0-19	CL	23	50	27	14	1.1	0.7	2.4
BE	19-33	SiCL	20	51	29	11	1.5	0.5	2.8
BW	33-46	SiCL	15	54	31	12	1.4	0.9	2.5
BK	46-84	L	26	49	25	2	1.0	1.0	2.6
C	84-119	SiCL	95	58	33	6	2.2	19.0	0.8
2Bwb	119-152	SiCL	19	51	30	8	15.6	28.0	0.8
Belfield									
Ap	0-18	SiCL	11	57	31	11	1.8	0.7	1.5
A	18-33	SiCL	17	49	34	11	1.1	0.7	3.8
EB	33-51	SiCL	12	52	36	13	0.5	0.9	3.4
BE	51-66	C	17	38	45	20	0.4	0.8	2.2
Bt	66-102	C	13	39	47	20	0.6	1.5	1.3
Btk	102-130	CL	20	44	35	5	0.5	1.5	0.9
2C	130-152	SL	69	19	11	0	0.6	1.9	1.2
2C2	152-172	Lfs	81	9	9	3	0.5	1.9	0.7

* extractable Ca/Mg ratio

A Comparison of Soils to Wetland Hydrology in North Dakota

J.L. Arndt and J.L. Richardson

Department of Soil Science
North Dakota State University
Fargo, ND 58102

Abstract. The morphology and selected physical, mineralogic, and chemical characteristics of pedons collected in seven North Dakota wetlands was examined to investigate the development of hydric soils associated with wetlands of the Northern Plains. The wetlands were representative of distinct ground-water recharge, flowthrough, and discharge conditions. All profiles collected in recharge wetlands were non-saline, free of carbonate, and exhibited clay illuviation to some degree, the result of seasonal ponding, fluctuating water-tables, and downward, saturated water flow characteristic of recharge conditions. Recharge profiles also exhibited continuous sediment aggradation due to erosion of the surrounding upland and deposition in the wetland. High organic matter production under such conditions resulted in overthickened A-horizons. Soil classes ranged from Typic Argiaquolls (Humic Luvic Gleysols) if argillic horizons were present, to Cumulic Haplaquolls (Orthic Humic Gleysols) if illuviation was not as well expressed. Soil development in the wet-meadow and shallow-marsh zones of flowthrough wetlands was influenced by higher, more stable, more brackish water-tables. Profile morphology reflected a continuum from dominantly-recharge to dominantly-discharge hydrology. All profiles were calcareous. The more saline profiles also contained gypsum. Soil classes ranged from Cumulic Haplaquolls of calcareous, mixed mineralogy to Typic Calciaquolls (Carbonated Orthic Humic Gleysols). The presence of high, saline water-tables and mechanical sorting of soil surfaces by wave action retarded soil development in the discharge wetland periphery. Soils were uniformly saline, calcareous, and gypsiferous. Soil classes ranged from Fluvaquentic Haplaquolls to Typic Fluvaquents (Carbonated Orthic Gleysols and Carbonated Rego Gleysols, respectively).

INTRODUCTION

Wetlands are an important landform in the glaciated Northern Plains of Canada and the United States, both from an ecological as well as an agricultural and management perspective. Soil is an important physical component of these wetlands (Cowardin et al. 1979), yet little descriptive information about the morphology and development of hydric soils of the Northern Plains is available.

Previous investigation has shown that information about local and regional ground-water flow systems in the glaciated Northern Plains can be obtained without detailed hydrogeological study by examining the effects of topography and ground-water movement on wetland plant communities and wetland soils. Rozkowski (1967), Eisenlohr and Sloan (1968), and Sloan (1972) established a direct relationship between ground-water discharge characteristics and wetland salinity. Stewart and Kantrud (1971, 1972) developed a wetland classification system specific to the Northern Plains relating hydrology to salinity and wetland flora. In their system, zonal plant communities reflect ponding duration, with species composition within zones controlled by salinity.

A hydric soil is defined as a soil that, in its undrained condition, is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation (Soil Survey Staff 1985). The concept of depression-focused recharge and discharge developed by Lissey (1971) has recently been used to evaluate the genesis, morphology, and chemistry of hydric soils in the Northern Plains. Specific investigations have considered soil-hydrology relationships in morainal prairie landscapes (Miller et al. 1985), in individual wetlands (Mills and Zwarich 1986), and a particular wetland type (Bigler and Richardson 1984, Richardson and Bigler 1984). However, a systematic examination using accepted, easily-identifiable field characteristics to evaluate local hydrology and its relation to salinity and hydric soil development in Northern Plains wetland systems has not been done. The present paper centers on the hydrology, general morphology, and salinity of hydric soils of dynamic wet-meadow and shallow-marsh zones in a recharge-flowthrough-discharge wetland system in North Dakota.

MATERIALS AND METHODS

Geology, local topography, proximity of area wetlands to each other, and the Stewart and Kantrud (1971) wetland classification system were used in the present study as field characteristics to identify locally-developed recharge-discharge wetland systems.

Description of the Study Area

A site was selected in sections 1 and 12, T151N R58W, Nelson County, North Dakota that met the following criteria: high wetland densities; wetlands in relatively homogenous glacial materials; and pondwaters exhibiting a wide salinity range. Salinity designations and ranges used in the present study to evaluate plant communities, ground water, and surface water (Table 1) are those of Stewart and Kantrud (1971).

The selected wetlands are in an elevated, hummocky area consisting of collapsed glacial sediments surrounded by rolling ground-moraine. Land elevations range from 456-474 m above sea level (mASL). Glacial deposits consist mainly of dead-ice facies of Coleharbor Formation till, which include calcareous as well as shale materials. Minimum till thickness in the study area ranges from 10 to 30 m over Pierre Formation shales (Bluemle 1973). The study area has a subhumid, continental climate. Summers are usually warm with a high evaporative demand. Winters are very cold with frequent surges of arctic air. A large portion of the average annual precipitation is received during spring, summer, and fall, with the greatest amounts occurring in spring and early summer. Winter snowfall is moderate and is often blown into drifts that accumulate in sheltered and low areas, leaving poorly-vegetated cropland free of snow (Doolittle et al. 1981).

Electrical conductance (EC), plant species composition, and approximate elevations of wetlands in the study area were surveyed in June, 1984. Wetlands varied in elevation from 455 to over 466 mASL. Pondwater EC ranged from 0.31 to 13.2 $dS \cdot m^{-1}$. On the basis of these data, seven wetlands with linked recharge-flowthrough-discharge relationships were selected for detailed study. The catchment basin and ponding basin for each wetland was delineated on acetate overlays of 1:20,000 scale aerial photographs. Basin areas were then calculated using computer digitization procedures.

Sampling Procedure

Pedons were described and classified using standard soil-survey methods (Soil Survey Staff 1951, 1975) and sampled in transects across the wet-meadow and shallow-marsh zones of each wetland during August 1984. Pedons collected in seasonal (Class III) recharge wetlands represent the entire wetland, from the central shallow-marsh to the peripheral wet-meadow zone. In more permanent Class IV wetlands, both these zones were peripheral to central deep-marsh or open-water zones that reflect more permanently-flooded conditions (Figure 1). In order to compare hydrologically similar soils between wetlands, deep-marsh soils are not considered in the present study. For further information regarding deep-marsh soils in the Northern Plains, see Bigler and Richardson (1984).

Soil samples were collected in 15 cm increments to 105 cm. A cross-section of the study area indicating the study wetlands and the approximate water-table configuration at the time of sampling is presented in Figure 2. A plan view of the study area indicating the location of wetlands and sample transects is presented in Figure 3.

Laboratory Methods

To a large degree, solution EC is a collective measure of dissolved ions, with the exact relationship dependent on the ions involved. Pondwater and ground water in the study area is strongly sulfatic (Arndt and Richardson 1986). The derivation of this chemistry is quite complex and is discussed in Hendry (1986) and Mermut and Arshad (1987). However, in solutions dominated by sulfate (SO_4^{2-}), the relationship of EC (as $uS \cdot cm^{-1}$) to total dissolved salts (as $mg \cdot L^{-1}$) is nearly 1:1 (Eisenlohr 1972, Hem 1982). Thus EC can be used to evaluate overall salinity. Ground-water and soil saturation-extract EC was determined using the methods of Rhoades (1982).

In addition to EC, particle-size and organic carbon content assist in discriminating hydric soils of the Great Plains (Richardson and Bigler 1984). In this study, particle-size analysis was by the hydrometer method of Day (1965), with sand fractions determined by sieving. Organic carbon was determined by the Walkley and Black (1934) method, using a correction factor developed for use in wetland soils (Richardson and Bigler 1982). Because accumulation patterns of calcite and gypsum reflect both the direction of ground-water flow and the intensity of solution concentration along the flow path (Timpson et al. 1986), calcite ($CaCO_3$) and gypsum ($CaSO_4 \cdot 2H_2O$) are included in the present study. Gypsum and calcite were determined using the methods of Williams (1948) and Nelson (1982), respectively.

RESULTS AND DISCUSSION

Area Wetland Hydrology

Sloan (1972) noted that pond permanence, salinity, and size often increase as ground-water discharge increases relative to other water inputs. Precipitation inputs directly to the pond are relatively fresh compared to groundwater inputs. Thus the salinity of pondwater is normally dependent upon the ratio of dissolved solids discharged to the pond in ground-water inflow (TDS-in) to dissolved solids removed in seepage outflow (TDS-out). If TDS-in exceed TDS-out, evapotranspiration concentrates the dissolved solids discharged to the pond. Conversely, if TDS-out exceed TDS-in, there will be a net removal of dissolved solids (Eisenlohr and Sloan 1968). These relationships are summarized in Figure 4. This hydrology results in an inverse relationship between catchment area/pond surface area ratios and permanence of ponding as determined by plant communities and salinity (Table 2).

Recharge Wetlands

Wetlands 2, 22, and 23 are typical of ponds that recharge the water table. Catchment areas are large relative to pond surface areas (Table 2). Because these are fresh, upland ponds, observed during the study to contain water continuously only in spring and early summer, a large catchment area to pond surface-area ratio indicates that recharge is primarily from fresh, snowmelt-derived runon. These ponds typically were dry by midsummer, after which temporary ponding occurred only after intense summer thunderstorms.

Flowthrough Wetlands

Flowthrough wetlands 1, 18, and 19 reflect varying degrees of recharge-discharge dominance. Wetlands 1 and 19 are quite similar in their physical and hydrologic characteristics. Catchment area/surface area ratio, permanence, landscape position, and salinity are intermediate between distinct recharge and discharge conditions, but are dominated by recharge characteristics (Table 2). Wetland 18 represents flowthrough conditions where discharge is dominant. It is lower, larger, more permanent, more saline, and has a considerably smaller catchment area/surface area ratio than wetlands 1 and 19. The position of this wetland in the landscape indicates that it receives groundwater discharge from topographic highs to the south, east, and west, and recharges the ground water to the north.

Discharge Wetland

Pond 20 represents a discharge condition. It is the largest and most permanent of the wetlands studied, yet its low catchment area/surface area ratio indicates a water balance with a small runon component. It is the lowest pond in the study area and is surrounded by topographically higher, slightly to moderately-brackish flowthrough wetlands similar to ponds 18 and 19. A significant portion of ground-water recharge from these flowthrough ponds is ultimately discharged to pond 20, producing a large, stable, brackish discharge component to the ponds' waterbalance. Evaporative concentration of this water results in a subsaline semipermanent pond.

Hydric Soil Morphology, Classification, and Salinity

Throughout this discussion we will use the terminology and classification nomenclature of the USDA Soil Conservation Service. The classification system is genetic and hierarchical in nature and thus provides a shorthand description of the soil classified along with information specific to soil formation. For example, a Cumulic Haplaquoll, fine-loamy, mixed (calcareous) soil is in the Mollisol order, indicating a highly base-saturated mineral soil with high amounts of organic carbon in the surficial horizons. It is further classified into: the Aquoll suborder, providing information relating degree and duration of saturation to several morphological features; the Haplaquoll great group, indicating that it is typical of the Aquoll suborder; and the Cumulic Haplaquoll subgroup, which indicates a relationship between landscape position, sedimentation rates, and organic carbon distribution. Finally this soil is in the fine-loamy, mixed (calcareous) family, which provides information on particle size and parent material lithology. Soil classifications to the family level are fully explained in Soil Taxonomy (Soil Survey Staff 1975).

Hydric Soils of Recharge Wetlands

The classifications of pedons collected from wet-meadow and shallow-marsh zones of recharge wetlands (Table 3) reflect the hydrology, geomorphology, and sedimentary history of these basins. All recharge pedons are classified into the Aquoll suborder, and are uniformly deep, well-developed, and fine-textured. Sediment and water inputs to these wetlands come primarily from overland flow during spring snowmelt and high-intensity thunderstorms (Lissey 1971). The upland catchment area of recharge wetlands is quite large relative to the wetland basin itself (Table 2). Erosion of these uplands provides substantial quantities of fine-textured alluvium. Particle size distribution in the basin reflects the sedimentation processes involved in transport and deposition of this alluvial material. Because larger, heavier particles settle first upon discharge to the pond, edge (wet-meadow) soils are significantly coarser than the soils of the interior shallow-marsh ($F = 9.53$, $p < 0.01$; Figure 5). Wet-meadow soils are generally in the fine-loamy family, with the fine family dominant in the interior shallow-marsh soils (Table 3).

Organic matter production in seasonal and semipermanently-ponded wetlands is extremely high over the entire wetland area (Fulton et al. 1986). A high rate of organic matter production coupled with continuous sedimentation results in overthickened A horizons developing in relatively homogenous fine-textured materials (Soil Survey Staff 1975; p. 280). Organic matter content of pedons collected in recharge wetlands is quite high in the surface and decreases gradually with depth (Figure 6). This organic matter distribution morphology is reflected in the Cumulic subgroup designation characteristic of the recharge pedons unless superceded by an argillic great group.

The Argiaquoll great group indicates that clay illuviation has become the dominent pedologic process. Periods of wetting and drying and leaching of carbonates and salt are needed for illuvial B-horizons to develop by silicate clay translocation (Thorp et al. 1959, Soil Survey Staff 1975). All recharge profiles are well developed, with illuvial clay in the B horizons. The presence of argillic (Bt) horizons in the wet-meadow zones and platy structure described in the E and A2 horizons of pedons from the shallow marsh reflect leaching and seasonal wetting and drying characteristic of recharge pond hydrology. Recharge profiles are also nonsaline and free of carbonates (Table 3), the result of leaching due to seasonal ponding with fresh water and downward saturated water flow. Miller et al. (1985) also found this to be characteristic of recharge wetlands in Manitoba.

Depth to water table in recharge profiles varied widely with season, and illustrates the relative wetting and drying intensity in these soils. Mean watertable depth for groundwater samples collected seasonally over a period of one year in the shallow-marsh and wet-meadow zones of wetlands 2, 22, and 23 was 0.95 m (SD = 0.50 m). Maximum depths in the wet-meadow zone ranged from 0.5 m to over 2 m in fall 1984, to ponded conditions for all wetlands in spring 1985. Thus the late-spring pond represents the top of a ground-water mound that progressively flattens as drawdown occurs over summer, resulting in a period of leaching and clay translocation. Clay illuviation is better expressed in the wet-meadow zones, likely the result of shorter periods of inundation and more intense wetting and drying in these pedons. Usually enough clay was present in the B horizons of wet-meadow pedons to permit an argillic great group designation (Soil Survey Staff 1975; p. 27).

Hydric Soils of Flowthrough Wetlands

The important hydrologic characteristics differentiating soil development in flowthrough wetlands from that occurring in recharge wetlands are increased pond permanence and the presence of brackish water at or near saturation with respect to calcite and gypsum. Flowthrough pedons are uniformly more saline than those of recharge wetlands (Table 3), reflecting a larger, more saline ground-water discharge component to the pond water-balance. All wet-meadow and shallow-marsh pedons are calcareous to some degree, and often exhibit calcic horizons permitting classification into the Calciaquoll great group (Soil Survey Staff 1975; p. 45, 276). The more saline profiles usually contain gypsum.

When present, calcite and gypsum are heterogenously distributed in the profiles, with standard deviations of profile means often exceeding the means themselves (Table 3). Concentrations are typically low or absent in the surface horizons of flowthrough profiles, with accumulation zones occurring deeper in the profile. Seasonal water-level fluctuations at the pond periphery explain these results. Steinwand and Richardson (1987) observed that flowthrough wetlands often contain gypsiferous zones distributed heterogenously in soils of the wetland periphery, with accumulations resulting from higher evapotranspiration at the wetland edge. By definition, wet-meadow and shallow-marsh zones represent the effects of temporary and seasonal ponding, respectively (Stewart and Kantrud 1971). Thus the soil surface in these zones is unsaturated for a significant portion of the year. During spring recharge, these zones are flooded with relatively fresh, snowmelt-derived water. Gypsum and calcite precipitated in the soil surface by evapotranspiration during summer drawdown would dissolve in this fresher water, while permanently saturated zones deeper in the profile would tend to retain their salts.

There was no evidence of clay translocation in flowthrough-wetland pedons, the result of lack of wetting and drying cycles associated with large frequent water-table fluctuations. Mean watertable depth for groundwater samples collected seasonally over a period of one year in the shallow-marsh and wet-meadow zones of wetlands 1, 18, and 19 was 0.59 m (SD = 0.49 m). The presence of Ca^{2+} in equilibrium with calcite or gypsum in these pedons also would retard clay dispersion necessary for translocation (Buol et al. 1973, Soil Survey Staff 1975). Organic matter production in these ponds is quite high, and in areas that receive large amounts of local alluvium, Cumulic Haplaquolls with mixed (calcareous) mineralogy were present (Table 3).

Hydric Soils of Discharge Wetlands

Discharge wetland data indicate a continuation of the trends developed in the flowthrough pedons. Water tables in these pedons were high and stable. Mean watertable depth for groundwater samples collected seasonally over a period of one year in the shallow-marsh and wet-meadow zones of wetland 20 was 0.19 m (SD = 0.13 m). Profiles are calcareous, gypsiferous, and saline (Table 3). Permanent open water was present in the center of the pond at all times during the study, in spite of the fact that the catchment area/surface area ratio indicates a very small runon component to the water balance.

Permanent ponding and high, stable, saline water-tables have prevented clay translocation and limited plant density and productivity. Because the catchment basin is just slightly larger than the pond basin (Table 2), deposition of eroded upland material in the wetland does not influence soil particle size as much as reworking of pond bed materials. Particle size distribution in all four profiles collected indicated a considerable quantity of sand in the surface, likely the result of periodic wave action mechanically sorting the shoreline material in this semi-permanent pond. This hypothesis is strengthened by the occurrence of discontinuities great enough to require contrasting particle-size family designations in transect 20a profiles (Table 3). This transect was located in a poorly vegetated area on the southwestern shore of the pond, directly in line with wave action associated with prevailing northwesterly winds. Transect 20b was located in a more sheltered area. Sorting was not as distinct and profiles were better developed.

In Soil Taxonomy (Soil Survey Staff 1975), the entic modifier is indicative of soils that have little or no evidence of development of pedogenic horizons. It is used in soil classification at the order and subgroup levels (Soil Survey Staff 1975). Low sedimentation and organic matter production rates, permanent high, saline water-tables, and periodic disturbance of profile surfaces by wave action have retarded soil development in the wet-meadow and shallow-marsh zones of the discharge wetland. Soil classes range from Fluvaquentic Haplaquolls to Typic Fluvaquents (Table 3).

CONCLUSIONS

1. Wetland soil development in hummocky till landscapes in the Northern Plains results from depression-focused recharge-discharge hydrology. The recharge-discharge hydrology for a particular wetland can be obtained through an examination of its position in the landscape, its permanence and salinity as reflected in plant communities, and the ratio of its catchment basin to its surface area.

2. Soil development in recharge wetlands is influenced by seasonal ponding, fluctuating water-tables, and downward, saturated water flow. These factors result in leaching of dissolved solids and clay translocation. All profiles were nonsaline, free of carbonate, and exhibit clay illuviation to some degree. Recharge profiles also exhibit continuous aggradation due to erosion of the surrounding upland and deposition in the wetland. High organic matter production under such conditions results in overthickened A-horizons. Soil classes ranged from Typic Argiaquolls if argillic horizons are present, to Cumulic Haplaquolls if illuviation was not as well expressed.

3. Soil development in the wet-meadow and shallow-marsh zones of flowthrough wetlands is influenced by higher, more stable, more brackish water-tables.

Profile morphology reflected a continuum from dominantly-recharge to dominantly-discharge hydrology. All profiles were calcareous. The more saline profiles also contained gypsum. Soil classes ranged from Cumulic Haplaquolls of calcareous, mixed mineralogy to Typic Calciaquolls.

4. The presence of high, saline water-tables and mechanical sorting of soil surfaces by wave action has retarded soil development in the discharge wetland periphery. Soils were uniformly saline, calcareous, and gypsiferous. Soil classes ranged from Fluvaquentic Haplaquolls to Typic Fluvaquents.

* This work has been accepted for publication in **Wetlands**.

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Table 1. Ranges in specific conductance of surface water in plant communities that are indicators of differences in average salinity*.

Plant community	Normal Range $dS \cdot m^{-1}$	Extreme Range $dS \cdot m^{-1}$
Fresh	0.04-0.5	0.04-0.7
Slightly brackish	0.5-2	0.3-2.2
Moderately brackish	2-5	1-8
Brackish	5-15	1.6-18
Subsaline	15-45	3.5-70
Saline	45-100+	20-100+

* After Stewart and Kantrud, 1971. Salinity designations used to classify water in the present study apply to the normal range. Thus moderately brackish water ranges in EC from 2-5 $dS \cdot m^{-1}$, which is the same EC range normal to the moderately brackish plant communities.

Table 2. Physical and hydrologic characteristics of sample wetlands in the Nelson County study area.

Wetland	Elevation -mASL-	Surface[1] Area -ha-	Catchment[2] Area -ha-	Ratio[3]	Pond Permanence	Salinity[4]
----------Recharge Wetlands-----------						
2	461.2	0.31	1.79	5.70	seasonal	fresh
22	460.1	0.12	1.11	9.25	seasonal	fresh
23	461.4	0.14	1.12	8.30	seasonal	fresh
--------Flowthrough Wetlands----------						
1	459.9	0.78	3.49	4.49	seasonal-semipermanent	slightly brackish
18	457.5	1.80	5.49	3.05	semipermanent	moderately brackish
19	459.0	0.50	2.72	5.40	seasonal-semipermanent	slightly brackish
------------Discharge Wetland----------						
20	456.0	6.59	11.13	1.69	semipermanent	subsaline

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[1] -Surface area of wetland. Includes wet-meadow, shallow-marsh, deep-marsh (if present), and open water (if present).

[2] -Catchment area is land area that yields surface runoff to pond, including the pond area itself.

[3] -Ratio is catchment area/surface area.

[4] -Rating on surface water samples collected late spring, 1984 using Table 1.

Table 3. Soil classification and selected characterization data for profiles collected from the wet-meadow and shallow-marsh zones of Area wetlands.

Wetland Transect	Vegetation Zone	Soil Classification	Textural Family	EC[1] -dS m^{-1}-	Calcite[1] -%-	Gypsum[1] -%-
			Recharge			
22 A	Wet Meadow	Typic Argiaquoll	Fine-silty	0.55(0.34)	0	0
	Shallow Marsh	Cumulic Haplaquoll	Fine	0.53(0.24)	0	0
22 B	Wet Meadow	Typic Argiaquoll	Fine-loamy	0.46(0.30)	0	0
	Shallow Marsh	Typic Argiaquoll	Fine-loamy	0.39(0.23)	0	0
23 A	Wet Meadow	Typic Argiaquoll	Fine-loamy	0.39(0.16)	0	0
	Shallow Marsh	Cumulic Haplaquoll	Fine	0.43(0.19)	0	0
2 A	Wet Meadow	Typic Argiaquoll	Fine-loamy	0.51(0.20)	0	0
	Shallow Marsh	Cumulic Haplaquoll	Fine	0.60(0.31)	0	0
			Flowthrough			
1 A	Wet Meadow	Cumulic Haplaquoll	Fine-loamy	1.95(1.20)	2.61(1.28)	0.07(0.13)
	Shallow Marsh	Cumulic Haplaquoll	Fine-loamy	2.38(0.86)	0.46(0.64)	0.02(0.04)
19 A	Wet Meadow	Typic Calciaquoll	Fine-loamy	4.39(0.77)	11.31(4.77)	14.86(12.78)
	Shallow Marsh	Typic Calciaquoll	Fine	2.77(1.24)	13.97(14.57)	0.45(0.58)
18 A	Wet Meadow	Typic Calciaquoll	Fine	7.60(0.93)	16.01(11.16)	0.57(0.70)
	Shallow Marsh	Cumulic Haplaquoll	Fine	7.97(1.06)	5.47(3.50)	0.54(0.41)
18 B	Wet Meadow	Typic Calciaquoll	Fine-loamy	8.09(2.43)	12.61(3.16)	8.24(9.72)
	Shallow Marsh	Typic Calciaquoll	Fine-loamy	6.36(2.05)	11.73(4.52)	12.74(12.4)
			Discharge			
20 A	Wet Meadow	Typic Fluvaquent	Sandy over loamy	11.2(0.80)	9.79(2.04)	2.15(3.96)
	Shallow Marsh	Typic Fluvaquent	Sandy over clayey	16.6(1.00)	6.83(2.78)	2.16(2.52)
20 B	Wet Meadow	Fluvaquentic Haplaquoll	Fine-loamy	18.9(2.45)	10.70(3.45)	5.94(4.85)
	Shallow Marsh	Mollic Fluvaquent	Fine-loamy	25.7(2.90)	9.40(2.01)	6.24(7.19)

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[1] Mean profile values, based on seven 7.5 cm increments per profile. Textural families are based on laboratory particle-size analysis according to the methods of Soil Taxonomy (Soil Survey Staff 1975, p. 383). Standard deviations are in parentheses.

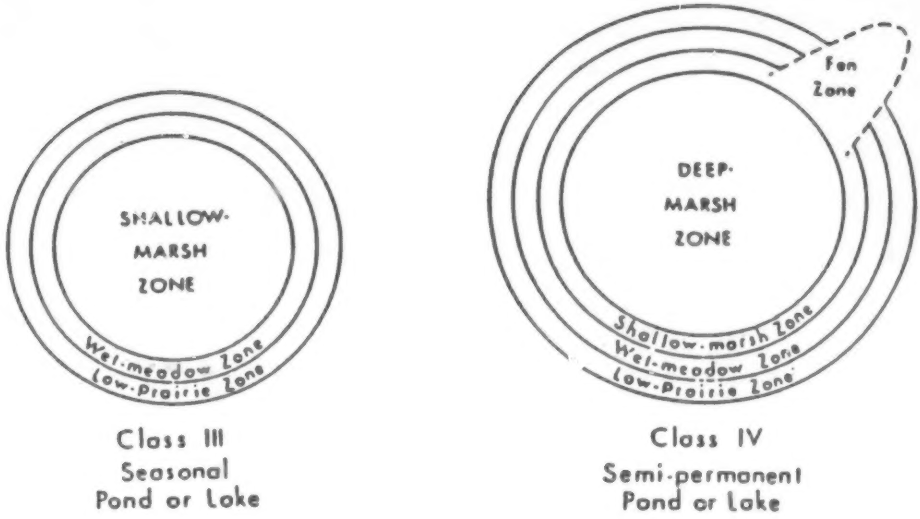
SHALLOW-MARSH ZONE
Wet-meadow Zone
Low-Prairie Zone
Class III
Seasonal Pond or Lake
DEEP-MARSH ZONE
Fen Zone
Shallow-marsh Zone
Wet-meadow Zone
Low-Prairie Zone
Class IV
Semi-permanent Pond or Lake

Figure 1. Class III and Class IV wetlands in the Stewart and Kantrud (1971) system, with diagnostic zonal plant communities indicated. Classes are ascribed according to the dominant central vegetation zone.

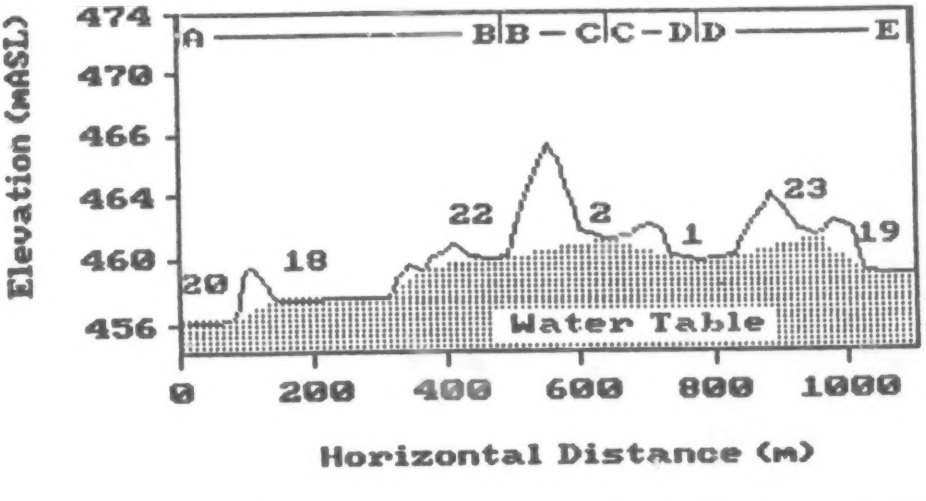

Figure 2. Crossection of the study area. Line segments at the top of the figure are in plan view in Figure 3. Numbers indicate sample wetlands.

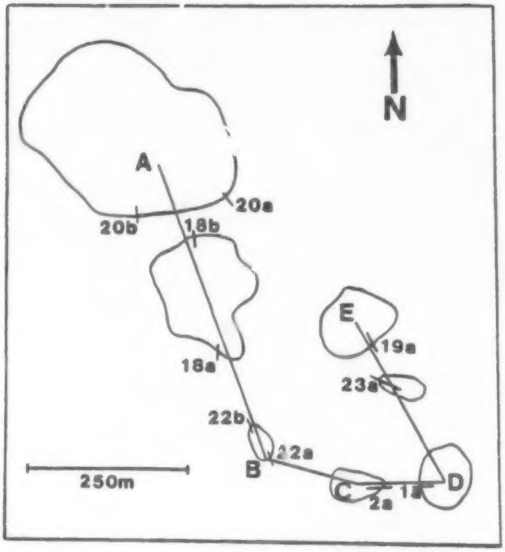
N
A
20a
20b
18b
18a
E
19a
23a
22b
22a
B
250m
C
2a
1a
D

Figure 3. Plan view of the study area. Upper case letters indicate crossection transect segments as seen in Figure 2. Lower case letters indicate sampling transects.

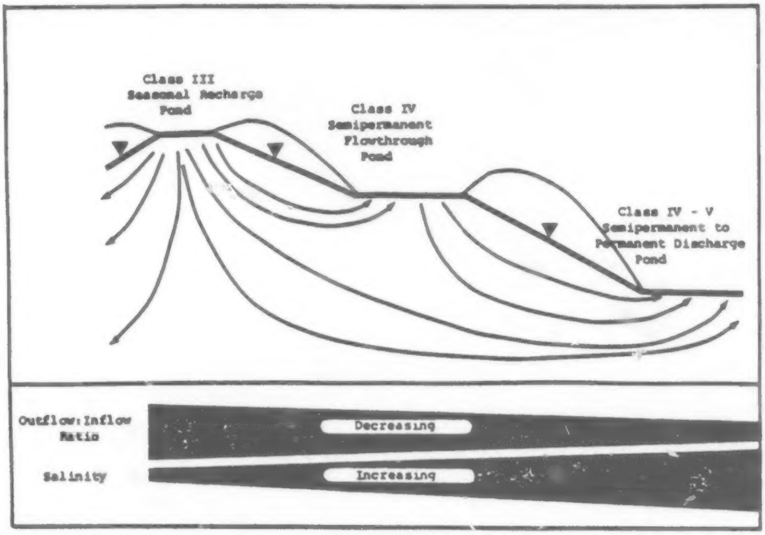
Class III
Seasonal Recharge
Pond
Class IV
Semipermanent
Flowthrough
Pond
Class IV - V
Semipermanent to
Permanent Discharge
Pond
Outflow:Inflow
Ratio
Decreasing
Salinity
Increasing

Figure 4. Generalized schematic of recharge-flowthrough-discharge pond hydrology in relationship to ground-water flow. Class numbers are those of Stewart and Kantrud (1971). Outflow:Inflow ratio is the ratio of TDS additions to the pond in ground-water seepage-inflow to losses in seepage outflow.

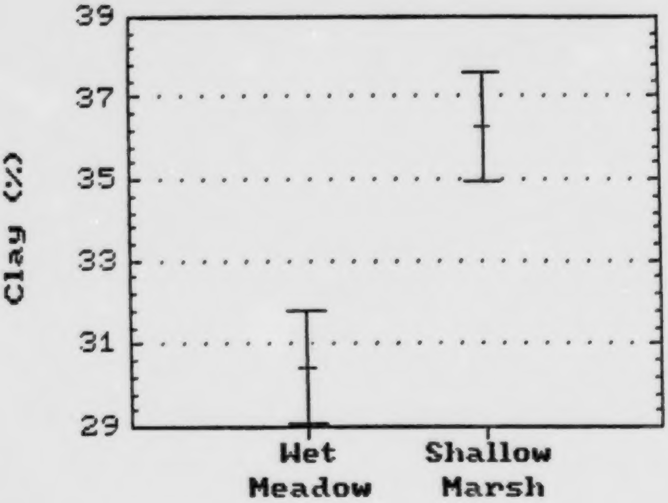

Figure 5. Mean clay percentages in wet-meadow and shallow-marsh profiles collected in recharge wetlands. Vertical bars indicate the standard error.

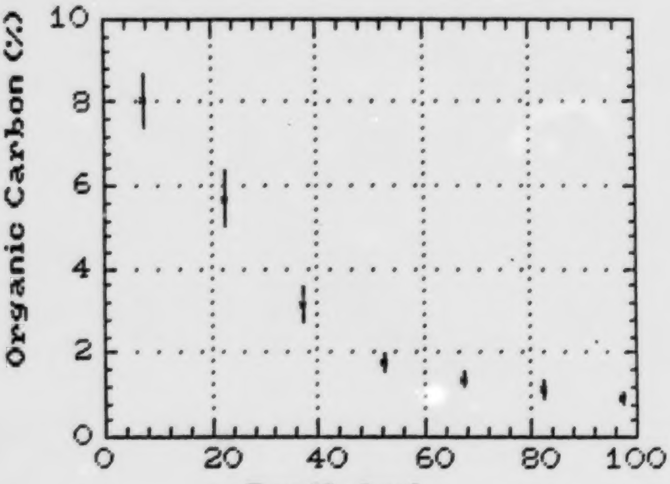

Figure 6. Mean organic matter content as a function of depth for profiles collected in recharge wetlands. Horizontal bars indicate the standard error.

THE ARGILLIC HORIZON IN CALCAREOUS NORTH DAKOTA TILL: RELATIONSHIPS AND CONDITIONS OF FORMATION

J.L. Richardson
Department of Soil Science
North Dakota State University
Fargo, ND 58105

INTRODUCTION

Bonger (1978) expressed his opinion that argillic horizons "in prairie soils of the United States, not only udolls, but also ustolls and even aridisols" ···"can not be explained by clay illuviation". He based his observations on micromorphology. He noted that three of the short grass prairie soils he examined in western United States were polygenetic and probably formed from older soil forming processes. Most of the soils , he believes, had a clay maximum because of a lithologic discontinuity in the parent material in his case loessial materials. I have worked with many of the loessial soils studied by Bonger. His "lithologic discontinuity" might be fine except that the discontinuity does not follow the loessial strata but does follow the ground surface or in other words the clay bulge almost certainly is due to soil not geologic conditions. His observations were 100% from single profile studies without regard for the stratigraphic and geomorphic setting. Additionally, as noted by Nettleton et al (1969), current processes cannot be inferred from the lack of argillans or "clay skins". In the present study my objective is to describe the conditions of argillic horizon formation in North Dakota. The focus will be on soils from calcareous till.

The classic argillic horizon, as defined in Soil Taxonomy (Soil Survey Staff, 1975), has an increase of at least 20% layer-lattice silicate clay from the overlying horizon. Much of this clay is presumably illuvial. The argillic horizon is the reference subsurface horizon in Soil Taxonomy, because all other subsurface horizons are contrasted to it. The assumption is that the clay is translocated as clay not as constituent parts and synthesized into clay. The reason for the assumption is the similarity of clay minerals in both the eluvial and illuvial horizons (Soil Survey Staff, 1975). Also the argillic horizon appears to take some time in forming and does not form in perhumid climates. Therefore the rationale that wetting and drying promotes the formation of an argillic horizon is commonly invoked. Additionally, calcium carbonate if it is finely divided tends stop clay translocation. Also forests are considered more conducive to the formation of an argillic than prairie grasses (Soil Survey Staff, 1975). The latter in fact is the basic thesis of Bonger (1978). Unless the soil has been influenced by forests an argillic horizon will not form, according to him.

DISCUSSION

In Figure 1, the Barnes loam, a soil that lacks an argillic horizon, is contrasted to four soils with argillic horizons. These soils with argillic horizons are representative of four conditions or circumstances of argillic horizon formation that are observed in North Dakota. The Kelvin series occurs under deciduous forests such as the woods in the Turtle Mountains on the Manitoba-North Dakota border. In landscapes older than Cary-aged till (the latest glacial event), the Williams series is common. If the till contains abundant sodium, a natric or solonetzic soil such as Miranda may occur or soils of the type mentioned in Seelig and Richardson's paper in this volume. In ephemeral, temporary, and some seasonal wetlands, soils with well defined argillic horizons such as the Tonka series are observed, such as Arndt and Richardson's paper in this volume.

Williams series

The Williams series, an Orthic Brown (Typic Argiboroll), contains a weakly developed textural B-horizon that commonly has just enough clay to qualify as an argillic horizon. The structure in these soils is, however, rather strongly developed. Frequently, the soil morphology reveals ped surfaces that certainly look like argillans or clay skins. Additional observations made by soil surveyors include: 1. the Williams normally occurs only in till that is older than Cary; 2. it occurs in the central and western potions of North Dakota with very distinct drying and wetting episodes; and 3. it occurs only on stable relatively uneroded landscapes. These soils have a smectitic mineralogy.

Using a multiple working hypothesis approach, three ready made hypotheses are made. 1. These horizons are not illuvial but are formed in place from intense wetting and drying which results in hydrolysis and clay synthesis. The action would have to be maximum in this horizon position in the soil profile which may be a possible weakness of the hypothesis. Glenn et al (1960) observed significant hydrolysis in a prairie soil with an argillic horizon but the maximum weathering he reported was in the A-Horizon. This particular hypothesis was mentioned by St. Arnaud and Whiteside (1964) quoting Acton (1961). In these studies, they were studying Orthic Black and Dark Brown soils in Saskatchewan. 2. These horizons are illuvial but are formed slowly over time as influenced by wetting and drying. This latter hypothesis favored by C. J. Hiedt (personal communication) and M. G. Ulmer (personal communication) is based on their observations that the Williams is best expressed in swale or runon positions. Ulmer notes that the years during glaciation were times of high precipitation and are the "critical years of formation." Soils near the glacier margins would receive a large amount of water. The extra water may be the factor here. 3. These horizons may be relict from the times when these landscapes were forested. Areas not glaciated in the last glacial advance were probably forested at least in part. Both the last two hypotheses could be true.

M. D. Sweeney (personal communication) believes that the Williams nearly always occurs on relict or very old landscapes. D. E. Van der Busch (personal communication) has conducted transects on several Williams landscapes. The Williams frequently occurs below the eroded portions of steep landscapes and on the lowest and more stable concave areas of long slopes. He believes that the combination of slope stability and the position on the landscape are the major factors for the formation of these soils. The Williams by appearances is an erosional remnant.

The best method for examining these hypotheses, in my opinion, would be a detailed field study of the landscape. The forest hypothesis would likely have the argillic horizons covering the entire area and the first two hypotheses would be more site specific. At present the author must accept all three hypotheses but favors the last two in these landscapes in North Dakota.

Kelvin series

Numerous authors have noted the influence of forests on the formation of argillic horizons compared to prairie vegetation (White and Riecken, 1955; St. Arnaud and Whiteside, 1964; White et al, 1969; Severson and Arneman, 1973; Soil Survey Staff, 1975; and Bonger, 1978). Severson and Arneman's (1973) study closely resembles the Kelvin-Barnes relationship. They studied the Nebish series (Gray Wooded or Typic Eutraboralf) that is closely related to the Kelvin and the Barnes series. The age of the landscape is younger than 12,000 years; the prairie forest transition is sharp with little intermediate or transitional soils between the Nebish and Barnes end members. The transitional soils resemble the Nebish or forest soil more than the Barnes in its chemical properties and illuvial horizon development. White and Riecken (1955) noted the same relationships in Iowa also.

Richardson and Riecken (1977) noted that the development of acidity is very different between forest and prairie soils. They attribute much of the chemical properties to the leaf disintegration and resulting carbonic acid weathering in forest and transition soils. The active soil organic matter tends to tie up divalent and trivalent ions. The calcium is spread throughout the prairie profiles. The calcium, I speculate, tends to stabilize the peds and slows or limits dispersion. The calcium content was high in the thin A-horizons and low in the E (Ae) horizons in the forest soils. In fact the eluvial horizons had consistently the lowest base saturation of all horizons in the soil. The pH was lower in the upper Bt horizons than in the eluvial horizons and the exchange aluminum was maximum in these horizons which would likely decrease the likelihood of dispersion clay in the Bt. The same profile pH distributions were noted by Severson and Arneman (1973).

I speculate then that the annual leave fall from deciduous trees contributes a very high source of cellulose and other easily oxidized and dissolved organic material ON the soil. The organic matter oxidation creates abundant carbonic acid. Carbonic acid removes calcium as calcium bicarbonate. This removal is especially noticeable in the eluvial horizon because the carbonic acid would pass readily to this horizon. The clays can then be dispersed readily on wetting if the calcium is removed. In our current work in North Dakota such as the paper in this volume by Seelig and Richardson, we have noted that lack of calcium is highly correlated to water dispersible clay in sodic soils. The clay in a mollic epipedon of prairie soils is associated with high amounts of divalent cations (Soil Survey Staff, 1975). The cations create dicarboxalate bonds between the organic matter and clay; these bonds appear to resist destruction. Also the clay-clay bonds are in a flocculated state in most prairie soils. Therefore the prairie soil does not contribute as much clay to the illuvial process as a comparable forest soil. Some clay can be contributed, however, and over long periods of time this amount can be significant. The matter of speed is important. If the wetting and drying process can be accelerated or the amount of water passing through the profile increased, large amounts of illuvial clay should be moved in prairie soils also. Duchafour (1982) relates a similar series of events in his section on pervection in his textbook.

Tonka series

In recharge focused wetlands, as described by Lissey (1971) for subhumid climates, water is gathered from the surrounding basin and concentrated in seasonal or temporary wetlands. The water recharges the groundwater below the wetland basin. Water moves downward into the soil and the water can move also laterally from the soil. In North Dakota, these argillic horizons occur in distinct basins with abundant water for leaching. The local water table reaches a maximum under these depressions and flows away from the basin. The wetlands in these basins are ephemeral, temporary and occasionally seasonal. The annual drying is characteristic. Semipermanent ponds are usually not leached.

The name Planosol was once used to describe a group of soils in humid regions of the United States that were formed under similar circumstances. The wetlands associated with this type of soil are broad upland types in summit positions such as those in southern Iowa (Richardson and Riecken, 1977) or poccosins on the coastal plain (Ray Daniels, personal communication). Water ponded in the wetter times of the year in the flat upland areas and then gradually flowed out through the soil.

The two important factors of the argillic development, I believe, are the very large amount of water that moves through the soil and the maximum wetting and drying that occurs. McCracken et al (1964) also notes that smectitic clay would aid in the development of the argillic horizon in these conditions. Schafer (1955) notes that the movement of water laterally is important. In his study the thin loess-covered upland in Iowa was underlain by a paleosol that lacked permeability. Those soils that had enough lateral water movement through the soil were leached and had highly developed argillic horizons. Other soils in the upland lacked the water movement. The stagnant water did not leach the soil free of calcium carbonate nor did an argillic horizon form.

Miranda Series

The Miranda is a solonetzic soil. The presence of the sodium ion is a well known and key feature in the evolution of these soils such as discussed by Seelig and Richardson in this volume. Sodium, a monovalent ion, would have little "flocculating power" or ability to create flocculation in a suspension (van Olphen, 1963). Van Olphen notes the following orders of magnitude of observed flocculating values and the smaller the number the larger the flocculating poser: 25-150 mmoles/L for monovalent ions, 0.5-2.0 mmoles/L for divalent ions, and 0.01-0.1 mmole/L for trivalent ions.

Therefore, as the amount of exchangeable sodium or other monovalent ion increases, the clay particles in a soil should become highly dispersion prone. Several properties of high sodium soils related to their "dispersive" nature effect their behavior in use. When these soils are dry, the clay platelets tend to orient face to face. The face to face packing is as dense as clay particles can be packed. The result is a hard, dense soil with high shear strength (dry cohesive strength). The old saying that "hard water makes soft land and soft water makes hard land" comes from the sodium in soft water creating the dense, strong hard, dry clods. Note, however, that when the soil is wet, the sodium or dispersive effect increases plasticity and decreases wet cohesive strength to a minimum. The platelets are repelling on another and the moisture allows for a maximum swelling on wetting. The result is the high plasticity and decrease in strength (Gerard, 1965). Another well known effect is that adsorbed sodium tends to decrease the permeability of soils. In materials similar to the tills discussed in this paper, Van Schaik (1967) noted that permeability became "negligible" if exchangeable sodium exceeded 15 per cent. Additionally the effect of sodium on soils is to increase the erodibility of the soils (Middleton, 1930) because the particles literally fly apart on wetting by the repellent action. In fact piping or tunnel erosion is often related to sodium. Sherard et al (1976) devised a test called the pinhole test based on the sodic effect of tunnel erosion as water passes through a soil. If the pinhole enlarges, the soil is subject to piping or has some quantity of water dispersible clay.

The speed of formation of an argillic horizon influenced by sodium is faster than in other conditions. The shrink and swell effects are at a maximum and the particles repel each on wetting and are readily mobilized or "eroded" (Sherard et al, 1976). In effect all macropores in the soil become "pinholes" and the dispersed soil is conducted into the soil rapidly. The pores are constricted at a shallow depth and the dry peds remove the water from the macropores leaving the translocated clay on the peds.

SUMMARY

The basic translocation process that moves clay from the eluvial to the illuvial horizon is by clay movement in macropores in suspension. Paton (1978) calls this process pervection. Pervection is a fundamental process that is analogous to tunnel erosion in that the particles are mobilized, transported in suspension and deposited. Something creates the dispersion in the surface (mobilization). Sodium is the most effective but hydrogen and carbonic acid of forest conditions are able to be effective also. Note also the effect of mobilization if wetting and drying is frequent such as in a recharge wetland. Once mobilized, the suspended particles are readily transported in macropores. Deposition occurs at constrictions or by drying the macropore of water when the peds are relatively dry and soak up the water.

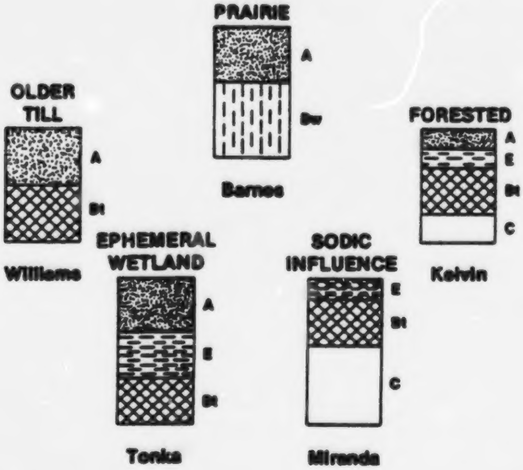
PRAIRIE
A
Bw
Barnes
OLDER TILL
A
Bt
Williams
FORESTED
A
E
Bt
C
Kelvin
EPHEMERAL WETLAND
A
E
Bt
Tonka
SODIC INFLUENCE
E
Bt
C
Miranda

Fig. 1. An array of soil series derived from calcareous till. Barnes is the "typical prairie soil and lacks an argillic horizon. The conditions for an argillic are older till, forested till, ephemeral and temporary wetland basins, and sodic-affected soils.

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SWAN RIVER FLOOD 1988

(Soil Erosion)

by B. Graham & J. Nickel

An abundance of melting snow that filled creeks and rivers to over capacity and additional precipitation (7.5") inundated the Swan Valley this spring. As a result 750,000 acres of agriculture land was not only flooded by severely damaged, as drainage channels were formed by rampaging water. Productive soils were moved downstream and eventually they silted in Swan Lake.

The tropograph has a great effect on the rate of flow of water from Duck Mountain on the south and Porcupine Mountains on the north. The water drops about 1000 feet to the farm land and the two major rivers and contributories, Swan River and Woody River take the flow to the Swan Lake Basin.

The soil erosion was so severe in fact that over 300 landowners applied to the Manitoba Disaster Assistance Board for help. This time, however, the provincial, federal and municipal governments decided that simply patching up the damage was not enough, it was time to take the conservation steps necessary to help prevent the consequences of similar disasters.

In all, the two year project will see about 1.2 million in repair costs shared by the three levels of government. Local farmers pay 25% of repairs with the average cost per gully pegged at about $3700 (original estimates).

Manitoba Agriculture and the MDAB were able to come up with an agreement where erosion gullies should be rehabilitated and stabilized. Generally the gullies needed to be shaped and sloped and gradient control structures, or small rock were constructed along the stream channel to lower the downstream gradient. River bank erosion was severe causing the rivers to jump out and create new channels depositing huge amounts of sediments. Losses of agricultural land have occurred due to both erosion and sedimentation.

The Swan River rehabilitation project will be covered under the following headings:

I. General information of the area, rainfall data and river and lake flows and levels.

II. Initial Investigation

III. Reconstruction Program

IV. Long term solutions and recommendations.

I. General Information of the Area:

A combination of climatic events during the first week in May resulted in the highest recorded runoff for the Swan River Valley. Accumulated snowfall in the upland headwater areas melted rapidly as a result of the high temperatures causing rapid snow melt. At the same time the area was hit by heavy snowfall coinciding with the snow melt runoff. Fall moisture supplies were 125% of normal and there was very little frost to hold the soil. The soil was mainly saturated by March 18, 1988.

Table I - shows rainfall data and snowmelt. The total precipitation with snow and rain was 7.55 inches.

Table II - gives the level of some lakes in the area and comparisons to previous levels. Swan Lake was 1.45 meters higher than the normal May level of 259.15. The Lake of the Prairies was 3.18 meters higher than normal May level of 429.9, the previous high was 430.2 in 1975.

TABLE I

Date	Snowfall		Water Equivalent	
	(inches)	(cm)	(inches)	(mm)
March 24 - 26	15.7	40	1.57	40
April 7 - 9	10.6	27	1.06	27
April 23 - 24	15.7	40	1.57	40
April 29 - May 2	-	-	2.76	70
May 6 - 8	-	-	0.59	15
Total	42.0	107	7.55	192

TABLE II

Dauphin - Swan River Area
May, 1988 Flood

LAKE LEVELS WITHOUT WIND
(Metres)

Lake	Predicated Level	1988 Peak Date	Normal May Level	Previous Maximum Level	Previous Maximum Year
Lake Winnipegosis	253.6	mid-May	253.17	254.2	1955
Lake Manitoba	247.7	late-May	247.58	248.7	1955
Dauphin Lake	260.7	mid-May	260.60	261.9	1974
Swan Lake	260.6^+	mid-May	259.15	260.2	1954
Lake of the Prairies	429.9	May 20	426.72	430.2	1975

+ Record High Level

The Swan River Valley has experienced runoff events in the past, which did not cause as severe water erosion as occurred in 1988. The streams in many locations have low capacity channels.

Table III shows the cubic meters per second of the various rivers.

TABLE III

Dauphin - Swan River Area
May, 1988 Flood

RIVER FLOWS
(cubic metres per second)

River	Estimated 1988 Peak	Normal Peak	Previous Maximum Peak	Previous Maximum Year
Valley River near Grandview	35	32	80.1	1976
Mink Creek near Ethelbert	20	4.6	44.2	1976
Fork River near Ethelbert	48	8.2	70	1976
North Pine River near Pine River	30^+	12	27.6	1984
North Duck River at Cowan	75	24	116	1962
Garland River [illegible] Duck River	65^+	9	35.5	1984
Roaring River near Minitonas	100^*	24	146	1976
Swan River near Minitonas	217	72	231	1963
Woody River near Bowsman	329^+	30	170	1963
Birch River near Birch River	40^+	8.0	22.8	1979
Steeprock River near Mafeking	100^+	29	94.3	1973
Shell River near Inglis	100^+	21	69	1976
Waterhen River near Waterhen**	190^*	160	317	1955

+ Record High Flow
* Predicted
** Peak Flows without wind

The Woody River was about 7 times the normal flow or 1% frequency (this event would occur 1 out of every 100 years). This river caused serious erosion, about $250,000 in restoration costs to soil erosion.

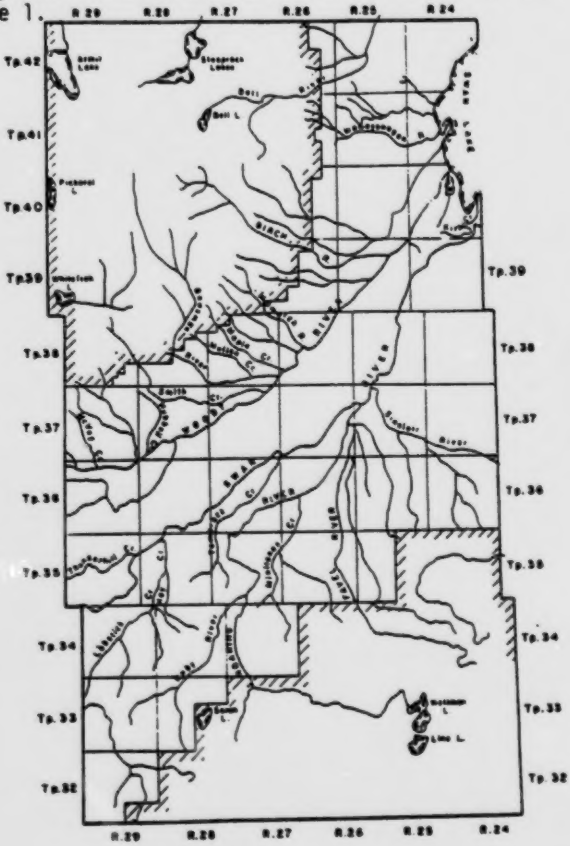
The frequency of flooding on some rivers are:

Woody River	**1%**	**(every 100 years)**
Roaring River	**1-2%**	**(every 100- 50 years)**
Swan River	**7%**	**(every 14 years)**
Birch River	**1&**	**(every 100 years)**
North Duck River	**5%**	**(every 20 years)**
North Pine River	**1%**	**(every 100 years)**
Garland River	**1%**	**(every 100 years)**

All rivers named above had record high flows.

The two rivers that channel the runoff in the valey to the Swan Lake are the Woody River and Swan River. This drainage system is outlined in figure 1.

FIGURE 1:


R.29
R.28
R.27
R.26
R.25
R.24
Tp.42
Tp.41
Tp.40
Tp.39
Tp.38
Tp.37
Tp.36
Tp.35
Tp.34
Tp.33
Tp.32
Bell
Bell L.
BIRCH R
Swan Lake
Smith Cr.
SWAN RIVER
Lime L.

The Woody River carries the major water from the Porcupine Mountains about 1 million acres. The Swan River carries the major water runoff of the Duck Mountains of about 1 million acres. There is about 1000 foot drop in elevation from the top of the mountains to the lower plain.

WATERSHED STATISTICS

Porcupine Mountains	4060 sq km	- 1568 sq.mi.
Duck Mountains	4230 sq km	- 1633 sq.mi.
TOTAL	8290 sq km	

or 3201 x 640 = 2,048,640 acres

II. Initial Investigation

There were about 300 applications for soil erosion damage on 500 quarter sections of land. The applications were picked up at the Municipal Offices and proceeded through the Manitoba Disaster Assistance Board. The applications were sent to the Ag. Rep. office in Swan River for processing. Six inspectors did the on-farm inspections. An inspection worksheet was prepared by Graham Sommers, Jacob Nickel and Bert Graham. Tables were prepared to estimate approximate cost of restoring the erosion damage.

The soil erosion inspection report (Fig. 2) consists of four main parts.

I. Description of the problem
II. Sketch of area and comments
III. Measurement Tables (L W D)
IV. Recommended Treatment and Cost Estimates

Each water erosion gully was measured in length, width and depth in meters.

Tables were established to estimate number of cubic meters required to restore the eroded areas. The permanent water runs are to be seeded to grass.

The tables (Table IV) are used to determine unit costs to restore erosion damage. The cost of moving the earth was estimated at $1.00 per cubic meter (includes fuel, labour and machinery).

eg. eroded gully has cut in field with following dimension in meters.

Depth .5 m, Width 7 m, Length 30 m

- To cu. meters required to restore gully for 10 meter length is 25 cu. meters
- The gully is 30 meters long, it will take 75 cu. meters to restore at cost of $1.00 per cu. meter and has a grass area of .9 of an acre (.03 x 3 = .9)

FIGURE 2

MANITOBA DISASTER ASSISTANCE BOARD

CLAIM FOR PAYMENT FORM

NAME OF APPLICANT: ______________________________

ADDRESS: ______________________________________ POSTAL CODE: __________

MUNICIPALITY/LGD: ______________________________

Please itemize the expenses incurred in the restoration of soil erosion which occured in 19__. Please attach receipts.

DATE	CONTRACTOR	MACHINE, MAKE, MODEL, AND/OR SERIAL NO.	HOURS	COST/HOUR	SUBTO
			TOTAL A		$

DATE	OTHER ITEMS			B
		TOTAL B		$
		TOTAL A & B		$

Estimate ______________

Actual Cost to Complete ______________

Actual Payable to Applicant (75%) ______________

Interim Payment (75% or 56%) ______________

Hold Back for Grass ______________

Payment to be made to Applicant ☐ or contractor(s) ☐

If contractors, complete reverse side of this form.

NOTE: The holdback applies when work is not completed. i.e. not seeded to grass.

I hereby certify that the above costs were incurred in the completio of the erosion restoration work and were authorized within the Cost Estimate Procedures.

DATE: ______________ ______________
Applicant

______________ ______________
Recommended for approval Inspector

____
Approved Board Chairperson

FIGURE 2

THE MANITOBA DISASTER ASSISTANCE BOARD

SOIL EROSION INSPECTION REPORT

SHEET #_______

APPLICANT:____________________________ INSPECTOR:____________________________

ADDRESS: ____________________________ DATE:____________________________

LEGAL DESCRIPTION: QTR.______ SECT.______ TWP.______ RGE.______ E or W

DESCRIPTION OF PROBLEM: (i.e. type of erosion, source of water, deposition, etc.)

____

____

____

____

SKETCH OF AREA

COMMENTS

No.	D	W	L	Unit Vol	Total Volume	Unit AC	Total AC
Total				▨		▨	

MEASUREMENTS TABLES

I.D.	DESCRIPTION	DIMENSIONS	VOLUME	COMMENTS

RECOMMENDED TREATMENT & COST ESTIMATES

I.D.	TREATMENT	MACHINE	NO. UNITS	UNIT COST	SUB TOTAL $

TOTAL $ __________

ADDITIONAL CONCERNS____

TABLE IV

TABLE FOR ESTIMATING THE COST OF GULLY STABILIZATION BASES ON FORMULA PROVIDED BY GEORGE KLASSEN

Cost of moving earth over 10m at $1.00 per cubic metre
The side strip has top soil roled back then repaced over waterway.
Top soil removale and replacement is charged for each movement.

DEPTH [metre]	WIDTH	SIDE WIDTH (per side)	TOTAL CUBIC METRES	COST OF MOVING EARTH	ACRES PER 10 metr
0.5	1	1.5	11	$11	0.01
0.5	2	1.8	15	$15	0.01
0.5	3	2.1	17	$17	0.02
0.5	4	2.4	20	$20	0.02
0.5	5	2.7	22	$22	0.03
0.5	6	2.7	23	$23	0.03
0.5	7	2.7	25	$25	0.03
0.5	8	2.7	26	$26	0.03
0.5	9	3.0	27	$27	0.04
0.5	10	3.0	28	$28	0.04
0.5	11	3.0	29	$29	0.04
0.5	12	3.0	30	$30	0.04
0.5	13	3.4	30	$30	0.05
0.5	14	3.4	31	$31	0.05
0.5	15	3.4	32	$32	0.05
0.5	16	3.4	32	$32	0.06
0.5	17	3.4	33	$33	0.06
0.5	18	3.4	33	$33	0.06
0.5	19	3.7	34	$34	0.07
0.5	20	3.7	34	$34	0.07

The tables were used as a guide to give the farmer a figure to approach a discussion with a contractor. The tables were about 70% accurate. Some variables which caused some differences in estimates are: wetness of the soil, experience of operator, condition of equipment, amount of silt and debris, rock reinforcement and length of haul, clay soil to stabilize water run and soil for dykes.

III. Reconstruction Program

The main objective was to restore the damaged area and to try and implement some preventive measures. The basic approach on the majority of damage areas was to peel back the top soil and the side of the damaged area and slope the side to form saucer shaped grass waterways. The waterway would be seeded to grass for permanent protection.

The reconstruction program varied considerably depending on amount of damage that had been done. The gully repair work was broken into three categories.

A. major reconstruction - severe damage - $10,000 & up

B. damage area - $1300 - $5000

C. minor damage - $1200 and under

The farmer was not compensated for sheet erosion, (erosion less than .5 metres deep) this repair could be done with his own equipment.

Some of the activities which determined the category for repair are:

Category A

- cost of recontruction $10,000 +
- damage is close to major rivers or in flood plains area
- repair river bank where breakout occurred
- relandscape the area to allow farmer to move his equipment over area for hay production (reshape into grass waterway)
- build dykes
- remove silt and debris
- repair river banks
- reinforcement with rock
- drop structures
- pumping water
- culvert installations
- low level crossings
- clay deposits for fill and dyke material

Category B

- cost of repair ($2000 to $9000)
- the damage area occurred from secondary channel system and not from major rivers
- repair activities were similar to category A but to a lesser degree of damage
- clean out of existing channel to try keep water from cutting into fields adjacent to channels
- may require rock sturcture to slow down water flow

Category C

- cost of repair is less than $2000
- shallow runs, but deep enough to require some heavy construction equipment

Equipment required for overall project

- caterpillar and dozer, 4 wheel drive tractor 200+ hp and 10 yard scraper, grader, hydaulic hoe with bucket and the farmers own equipment.

IV. Long Term Solutions and Recommendations

The Soil Conservation District Authority is examining the feasibility of establishing a Conservation District in the valley (Swan River R.M., Minitonas R.M., L.G.D. of Mountain). Hopefully the approach will continue and result in a longer term examination of the problems and methods of preventing losses to municipalities in the area and are looking for ways of implementing soil conservation programs in the future.

The Swan River Valley is an area of rich alluviah soils (750,000 acres cultivated land) surrounded by higher ground of the Duck and Porcupine Mountains. Many of the streams channels are shallow with limited flow capacity. The need for an integrated approach involving the local municipal governments, Provincial government agencies including Agriculture and Natural Resources and the Federal government, notably PFRA, are essential to addressing the problem. Sometimes a crisis is needed to stimulate action. Swan River has experienced the crisis.

THE EFFECT OF DEEP RIPPING AND PARAPLOWING ON CROP PRODUCTION IN SASKATCHEWAN

M.C.J. Grevers
Saskatchewan Institute of Pedology
University of Saskatchewan, Saskatoon

Abstract

The feasibility of deep ripping and paraplowing in terms of improving crop production was investigated over a three-year period. A total of 13 sites from different soil zones were included in the study involving soils varying in texture and in solonetzic characteristics. The deep tillage operations involved deep ripping and paraplowing, which had been carried out in the fall. Following either deep tillage treatment, the soils tended to be less dense in the 10-50 cm depth, in the year following deep tillage. By the second year this trend had more or less disappeared. Both deep ripping and paraplowing increased soil water recharge for up to 2 years following the deep tillage operation. Crop emergence at some sites was decreased in the tillage plots, due to poor seedbed conditions. In some cases poor emergence resulted in reduced yields. Crop yield was significantly increased due to either deep ripping or paraplowing on solonetzic soils. Increases were more dramatic following deep ripping than following paraplowing. The yield increases lasted at least two years following the deep tillage operations, and at one site the yield increases lasted into the third year. Deep ripping and paraplowing increased yields on only one of the four mixed solonetzic/chernozemic soils, and in none of the 3 non-solonetzic soils. There was little effect of either deep tillage treatment on the percent protein in the crop.

Deep tillage has received much attention in the media over the past 4 to 5 years. Articles have appeared in farm publications such as Country Guide (November 1984) and GRAINEWS (September 1986), which indicated that with deep ripping crop production had been increased at particular farm sites. Furthermore, farmers have frequently reported on improved crop production in parts of their field following the installation of pipelines. In Saskatchewan, soil disturbance from the installation of pipelines has been found to increase soil productivity of solonetzic soils (de Jong and Button, 1973). There has been much discussion amongst the farm community in Saskatchewan regarding the deep tillage work in Alberta, such as on so-called "alkali soils" around Vegreville. Deep tillage in general is not recommended as a farm practice in Saskatchewan, particularly in areas sensitive to soil erosion and in areas with soil salinity problems. There was thus a need to investigate the feasibility of deep ripping under Saskatchewan conditions.

Deep tillage is defined as "a primary tillage operation which manipulates the soil to a greater depth than normal plowing" (American Society of Agricultural Engineers, 1971). Deep tillage or subsoiling is generally carried out to improve unfavorable characteristics of the subsoil such as plow pans and/or compacted layers (Russell, 1973). There is little evidence to suggest that soil compaction limits crop production in Saskatchewan (McConkey, 1987). On the other hand, solonetzic Bnt horizons have been found to severely limit crop production. These layers effectively reduce water infiltration into the soil, and subsequently reduce the amount of soil-water recharge over the winter period. In dry years, solonetzic "pockets" in a field are the first areas showing a crop under severe water stress.

Deep tillage of solonetzic soils has resulted in increased crop production in Alberta (Toogood and Cairns, 1978). Deep plowing of solonetzic soils results in both the disturbance of the impermeable layer, and the mixing of the Na-rich Bnt horizon with the Ca-rich C horizon. Generally, the physical and chemical properties of these deep plowed solonetzic soils are greatly improved (Cairns and Bowser, 1977). Much of the research on deep plowing of solonetzic soils has been done in Alberta (Cairns, 1961, 1962; Bowser and Cairns, 1967). In Saskatchewan, Ballantyne (1983) studied soil conditions and crop production following deep plowing of solonetzic soils north of Radville (near Weyburn). He found that the improved soil chemical conditions and crop growth from deep plowing persisted at least 5 years following deep plowing

Deep ripping is considerably less expensive than deep plowing, but may cause insufficient mixing of soil layers to result in significant improvement in the productivity of solonetzic soils (Alzubaidi and Webster, 1982). Bole (1986) found increased soil-water infiltration following deep ripping, however, the effect only lasted for 2 years. Alzubaidi and Webster (1982) found that deep ripping had resulted in increased deep leaching of salts. There has been little evidence to suggest that deep ripping results in considerable increases in crop yield of solonetzic soils (Lavado and Cairns, 1980). Lickacz (1986) reported that deep ripping of solonetzic soils was less beneficial in terms of increasing crop production in areas with severe moisture deficits, than in "wetter" areas. For example, he reported average wheat yield increases due to deep ripping of 130 kg/ha in the Brown soil zone compared to 400 kg/ha in the Dark Brown and Black soil zones.

Deep rippers or subsoilers, are used to loosen the soil without inverting it, and are used primarily to break through and shatter compact sub soils. Under most conditions subsoilers will break out a slot of soil that is slightly wider that the tool point (Cooper, 1971). The loosened soil resembles a triangular shaped trench (Bowen, 1981; Trouse and Humbert, 1959). Another type of subsoiler is the paraplow, which has been described as a "slant legged soil loosener" (Pidgeon, 1982). This tillage implement was originally designed to alleviate soil compaction in zero-tilled soils (Davies et al, 1982). Soil loosening is achieved through a lifting action along the legs of the plow, which results in the formation of cracks along natural planes of weakness (Davies et al, 1982). Soil loosening apparently is almost uniform with depth (Ehlers and Baeumer, 1988). Therefore, soil loosening with the paraplow is quite different from that with conventional subsoilers or deep rippers, where the soil is displaced forwards, sideways and upwards, leaving a V-shaped trench.

The objective of this research project was to investigate the effect of deep ripping and of paraplowing on the physical and chemical conditions of the soil and on crop production. A range of soil types were included, such as soils with varying degrees of solonetzic characteristics, with different textures and in different soil zones. The investigation was carried out over a three year period.

Materials and Methods

A total of 13 farm sites are included in the study, involving both deep ripping, ranging in depth from 50 cm to 76 cm and paraplowing to a depth of 50 cm (Table 1). The sites include 6 solonetzic soils and 7 chernozemic soils, representing the Brown soil zone (2), the Dark Brown soil zone (3) and the Dark Gray soil zone (8). In all cases deep ripping and paraplowing were carried out in the fall. On the majority of sites deep ripping was done with a KELLO-BILT subsoiler, pulled with a 1150 VERSATILE tractor (450 HP). Paraplowing was done with a HOWARD 3-bottom paraplow (courtesy of Agriculture Canada @ Swift Current). The paraplow was pulled with a DEUTSCH DX130 tractor (~120 HP) for most of the sites. At Tisdale, A BELARUS tractor (~250 HP) was used. At most sites, tillage strips were a 1/2 mile in length and 40' to 60' in width. The treatments were replicated three times. The strips were separated by a control area of similar dimensions. Secondary tillage operations, such as discing and harrowing to smooth down the deep-tilled fields were considerable, in particular at the Tisdale and Arborfield sites. At the Morgan farm,large depressions were left in the field, with subsequent exposed subsoil in some areas. At the Cragg and Chabot farms, subsequent secondary tillage operations in the spring had left the top 4" to 5" of the soil in a very dry and powdery condition for seeding.

Soil chemical criteria used to differentiate solonetzic soils from chernozemic soils are the exchangeable Ca/Na ratio and the % water soluble Na. A soil is considered to be solonetzic if the exchangeable Ca/Na ratio of the B horizon is equal to or less than 10 (Canada Soil Survey Committee, 1978). A solonetzic soil can also be identified, if the % water soluble Na in the B horizon is equal to or greater than 50% (Ballantyne and Clayton, 1962). Based on soil chemical criteria, 5 of the sites (Boxall, Morgan, Cragg, Warner and J. Eliason) are solonetzic, satisfying either the criteria for the exch. Ca/Na ratio for the B horizon or the % Water Soluble Na (Table 2). A further 4 sites (McEwen, Chabot, Riopka and D. Eliason) have at least one of the 6 sampled profiles (worst profile) that classify as "chemically" being solonetzic. The remaining 4 sites (Rice, Norrish, Jessiman and Millar) are non-solonetzic, and deep tillage is therefore not expected to improve crop production.

Table 1. Soil description and tillage details of the research plots

Site	Farm	Soil Zone	Soil Order	Soil Association	Year of Tillage	Depth of tillage
			Deep Ripped			
						(cm)
Tisdale	Boxall	D.Gray	Solonetz	Arborfield C-CL	1985	76
	McEwen	D.Gray	Solonetz	Arborfield C-CL	1985	76
	Morgan	D.Gray	Solonetz	Arborfield C	1985	76
	Rice	D.Gray	Chernozem	Tisdale SiC-SiCL	1986	76
Arborfield	Chabot	D.Gray	Solonetz	Arborfield C	1986	76
	Cragg	D.Gray	Solonetz	Arborfield C	1986	76
Lucky Lake	Jessiman	Brown	Chernozem	Sceptre HC	1986	50
Carrot River	Norrish	D.Gray	Chernozem	Tisdale C	1987	61
	Warner	D.Gray	Solonetz	Arborfield C	1987	61
Glenside	Riopka	D.Brown	Chernozem	Tuxford C	1987	61
	J.Eliason	D.Brown	Chernozem	Tuxford C	1987	61
	D.Eliason	D.Brown	Chernozem	Tuxford C	1987	61
			Paraplowed			
Tisdale	Boxall	D.Gray	Solonetz	Arborfield C-CL	1986	50
	McEwen	D.Gray	Solonetz	Arborfield C-CL	1986	50
Lucky Lake	Jessiman	Brown	Chernozem	Sceptre HC	1986	50
Birsay	Millar	Brown	Chernozem	Fox Valley CL	1986	50

Table 2. Soil chemical characteristics of the B horizons of the deep tillage sites.

Site	Farm	Means of all the profiles		Worst profile	
		E.C.N.[1]	P.W.S.S.[2]	E.C.N.[1]	P.W.S.S.[2]
Tisdale	Boxall	5	31	3	40
	McEwen	19	43	14	57
	Morgan	2	68	1	71
	Rice	133	14	110	19
Arborfield	Chabot	30	46	17	53
	Cragg	7	79	6	81
Lucky Lake	Jessiman	231	10	118	15
Carrot River	Norrish	121	8	97	12
	Warner	4	59	3	74
Glenside	Riopka	21	40	13	51
	J.Eliason	22	50	10	72
	D.Eliason	30	42	16	53
Birsay	Millar	30	22	27	23

1. Exchangeable Calcium to exchangeable sodium ratio
2. Percent water soluble sodium

Soil physical parameters that were measured include soil moisture, soil bulk density and soil strength. Soil water content was measured by neutron thermalization, using a DEPTH MOISTURE GAUGE (Troxler Electronic Laboratories Inc.). Soil bulk density was measured by gamma backscattering using a DEPTH DENSITY PROBE (Nuclear Chicago). A DEPTHPROBE CPN 501 (Hoskins Scientific) was used in 1988 for both the soil moisture and density readings. The scanning zone of the DEPTH DENSITY PROBE (Nuclear Chicago) has a vertical dimension of approximately 23 cm, while the scanning zone with the DEPTHPROBE CPN 501, has a vertical dimension of approximately 15 cm and is therefore more sensitive to "picking up" dense layers in the soil. Aluminum access tubes (2 per replicated plot) had been installed to a depth of 60 cm to facilitate the measurements of the soil bulk density and the soil moisture content in-situ, using the depth probes. Readings were taken prior to seeding (1 to 2 weeks) and at harvest time. Soil strength was measured with a Proctor penetrometer. This method involves pushing a probe into the soil and measuring the force required to do so. Penetrometer measurements were taken at the time of harvest at each crop sampling area.

Crop yield was determined by taking square meter samples, in a series of paired row samples, 6 pairs in each tillage strip. The samples were then transported to the University, where the samples were dried, weighed, threshed and analyzed for protein content, using a Technicon Infraalyzer 400D.

Results and Discussion

Soil Bulk Density

Measurements of soil bulk-density taken in the fall, indicated that the deep tillage operations had reduced soil density at the 10-50 cm depth (Table 3). The differences were not significantly different, except for the 1988 measurements. The data is indicative of the trends in soil bulk density. In general, the soil was less dense in the 10-50 cm depth one year following deep tillage. By the second year, the differences in soil bulk density had disappeared except at two sites; Morgan and

Table 3. Soil depths (cm) where the bulk density in the deep tillage plots was ≤0.05 gm/cm^3 than the bulk density in the control plots.

Site	Farm	Year of tillage	1986 fall	1987 fall	1988[1] fall
			cm		
		Deep Ripped			
Tisdale	Boxall	1985	10-50	n.d.	n.d.
	McEwen	1985	n.d.	n.d.	n.d.
	Morgan	1985	10-50	n.d.	10-30
	Rice	1986		10-50	n.d.
Arborfield	Chabot	1986		10-50	n.d.
	Cragg	1986		10-50	n.d.
Lucky Lake	Jessiman	1986	10-70	10-30	10-50
Carrot River	Norrish	1987			n.d.
	Warner	1987			30-50
Glenside	Riopka	1987			n.d.
	J.Eliason	1987			n.d.
	D.Eliason	1987			n.d.
		Paraplowed			
Tisdale	Boxall	1986	10-50	n.d.	30-50
	McEwen	1986	30-50	n.d.	n.d.
Lucky Lake	Jessiman	1986	10-50	10-30	10-30
Birsay	Millar	1986	10-30	n.d.	10-30

n.d. = no difference based on a t-test

Jessiman. At the Glenside sites there were no differences in bulk density one year following deep tillage. Deep ripping at the Glenside sites had been carried out when the soils were relatively "moist", which resulted in less soil disturbance than was the case at the other sites.

Soil-Water Recharge

Over-winter soil-water recharge was calculated from the soil moisture readings taken at harvest time (Aug/Sep) and in spring (April). The relative amount amount of soil-water recharge during this period therefore is indicative of differences in soil-water infiltration from rainfall and from melting snow, and of soil-water conservation during this period. Over-winter soil-water recharge in the tillage plots for 1986/1987 are listed in Table 4 and 5.

The average gain in soil moisture for the 1986/87 period, was 12 % for the control plots, 17 % for the deep ripped plots and 26 % for the paraplowed plots (Table 4). The average gain in soil moisture for the 1987/88 period was 23 % for the control plots, 26 % for the ripped plots and 24 % for the paraplowed plots (Table 5). The relative gain (cm H2O) in soil moisture in the deep tillage plots compared to the gain in soil moisture in the control plots for the first three years following the deep tillage operations is listed in table 6. The ripped plots gained an additional 1.1 cm and 0 cm, in the second and in the third year, respectively, following deep ripping. No measurements had been taken for the first year. The paraplowed plots gained an additional 3.4 cm and 1.2 cm, in the first year and in the second year, respectively, following the paraplowing operations. There does appear to be a positive effect of either deep tillage treatment on soil-water recharge over the winter period, and the effect may last up to 2 years.

Soil Strength

Soil penetrometer measurements were taken at the time of harvest and results are shown in table 7. The penetrometer measurements are easily carried out in the field and are therefore a very convenient type of measurement. Soil strength however, is dependent not only on soil density (i.e porosity), but also on soil moisture content. Since deep ripping and paraplowing

Table 4. Over-winter water recharge in the tillage plots for 1986/1987.

Site	Tillage	Soil moisture levels			
		Fall	Spring	Gain	% Gain
		---------	cm H_2O	---------	
Boxall	Control	34.5	40.8	6.3	18
	Ripped	36.3	42.6	6.3	17
	Paraplowed	34.5	43.6	9.1	26
McEwen	Control	35.4	45.8	10.4	30
	Ripped	34.4	45.8	11.4	33
	Paraplowed	35.4	51.3	15.9	46
Morgan	Control	34.8	34.0	-0.8	-2
	Ripped	34.4	37.6	3.2	9
Jessiman	Control	32.2	33.6	1.4	4
	Ripped	31.9	35.1	3.2	10
	Paraplowed	33.5	40.0	6.5	19
Millar	Control	26.7	29.7	3.0	11
	Paraplowed	26.9	29.9	3.0	11

Table 5. Over-winter water recharge in the tillage plots for 1987/1988.

Site	Tillage	Soil moisture levels Fall	 Spring	 Gain	 % Gain
			-----------cm H2O---------		
Boxall	Control	36.2	48.2	12.0	33
	Ripped	36.7	49.5	12.8	35
	Paraplowed	35.2	48.2	13.0	37
McEwen	Control	35.1	45.0	9.9	28
	Ripped	36.6	44.7	8.1	22
	Paraplowed	34.0	45.4	11.4	34
Morgan	Control	36.5	47.8	11.3	31
	Ripped	36.6	48.9	12.3	34
Rice	Control	27.6	35.0	7.4	27
	Ripped	23.8	30.0	6.2	26
Chabot	Control	40.7	50.7	10.0	25
	Ripped	36.8	46.9	10.1	27
Cragg	Control	37.8	52.6	14.8	39
	Ripped	36.6	53.1	16.5	45
Jessiman	Control	33.4	36.2	2.8	8
	Ripped	32.3	37.1	4.8	15
	Paraplowed	37.5	40.8	3.3	9
Riopka	Control	32.2	39.9	7.7	24
	Ripped	32.2	42.4	10.2	32
D.Eliason	Control	31.3	36.5	5.2	17
	Ripped	31.3	38.8	7.5	24
J.Eliason	Control	31.1	33.6	2.5	8
	Ripped	31.1	33.6	2.5	8
Millar	Control	25.2	27.8	2.3	9
	Paraplowed	25.6	29.8	4.2	16

Table 6. Increase in soil water recharge in the deep tillage plots relative to that in the control plots for the first three years following the deep tillage operations.

Site	Year #1	Year #2	Year #3
		Deep Ripping	
		--------------cm H2O---------------	
Boxall	n.d.	0.0	0.8
Morgan	n.d.	4.0	1.0
McEwen	n.d.	1.0	-1.8
Rice	n.d.	-1.2	n.d.
Chabot	n.d.	0.1	n.d.
Cragg	n.d.	1.7	n.d.
Jessiman	1.8	2.0	n.d.
Average	n.d.	1.1	0.0
		Paraplowing	
Boxall	2.8	1.0	n.d.
McEwen	5.5	1.5	n.d.
Jessiman	5.1	0.5	n.d.
Millar	0.0	1.9	n.d.
Average	3.4	1.2	n.d.

n.d. = no data

Table 7. Soil strength measurements in the top 40 cm in the tillage plots.

Site	Tillage	1986	1987	1988			
		7.5 cm	7.5 cm	10 cm	20 cm	30 cm	40 cm
		MPa					
Boxall	Control	1.65	0.76	1.75	2.67	4.00	4.25
	Ripped	1.16	0.73	1.25	1.50	1.68	1.50
	Parapl.		0.64*	1.75	4.63	4.38	4.88
McEwen	Control	8.25		4.79	6.58	7.71	8.13
	Ripped	6.58		5.14	6.72	7.61	7.83
	Parapl.			4.94	6.36	7.44	7.67
Morgan	Control	7.35	2.93	3.38	4.38	5.46	6.25
	Ripped	3.46	2.04*	3.00	4.46	4.96	5.13
Rice	Control			1.67	2.75	3.97	5.94
	Ripped			1.36	2.03*	2.86	3.50*
Chabot	Control		0.39	6.97	7.22	8.19	8.28
	Ripped		0.38	6.47	7.14	7.94	8.03
Cragg	Control			5.61	6.36	6.94	7.28
	Ripped			4.92	5.78	6.33	6.67
Jessiman	Control		0.92	2.92	5.33	4.78	6.03
	Ripped		0.60*	2.56	3.53*	4.72	5.53
	Parapl.		0.75*	2.47	3.92	5.56	6.58
Norrish	Control			2.97	4.19	5.28	5.67
	Ripped			2.56	3.50	4.56	4.94
Warner	Control			5.44	5.56	4.89	4.94
	Ripped			4.25	4.83	5.06	5.46
Riopka	Control			1.46	2.31	3.60	4.33
	Ripped			1.17	2.01	2.94	4.25
J.Eliason	Control			0.92	1.47	2.19	3.00
	Ripped			0.94	1.81	2.56	3.92
D.Eliason	Control			2.61	5.06	6.19	6.53
	Ripped			2.33	4.08	5.75	6.58
Millar	Control		3.99	0.72	1.81	2.28	3.08
	Parapl.		4.96	0.64	1.44	1.94	2.53

Values followed by a * indicate significantly different from the value for the control affect the soil density directly and soil moisture indirectly, the penetrometer measurements may become of little value for indicating differences in soil density in cases where soil moisture contents are not similar. In the three years of data presented in table 6, there were a number of instances where soil moisture contents amongst the tillage plots were quite different.

In 1986, the soil strength in the deep ripped plots at 7.5 cm depth was less than the soil strength in the control plots for all the three sites. The soil moisture content at this depth (not shown) was also greater in the ripped plots. Consequently the differences in soil strength do not necessarily indicate differences in soil porosity. In 1987, there were two sites where deep ripping had resulted in reduced soil strength (Morgan and Jessiman), and two sites where paraplowing had reduced soil strength (Boxall and Jessiman). The soil moisture contents for these sites was similar amongst the tillage plots. In 1988, a more thorough investigation of soil strength with depth, revealed very little significant differences due to either deep ripping or due to paraplowing. In general, a trend in the data showed that deep ripping had reduced soil strength at the 20 and 40 cm depths, while paraplowing had reduced soil strength primarily at the 20 cm depth.

Crop Production

Crop growth was monitored during the growing season and harvest samples were taken one week prior to the farmer swathing the field (Table 8). There were considerable plant emergence problems in the first year after deep ripping at 6 sites; Boxall, McEwen, Morgan, Cragg, Chabot and Norrish. In each case spring secondary tillage operations required to "smooth down" the seedbed in the ripped strips, had resulted in relatively poor seedbed conditions (dry and loose). Seeding was carried out without adjusting for the different seedbed conditions that existed in the ripped strips. Crop emergence in the ripped areas was uneven and often delayed. In 1986, timely spring rains alleviated the crop emergence problems at the Boxall, McEwen and Morgan sites. The crop in the ripped areas recovered and eventually outyielded the crop in the control areas at these sites.

Table 8. Crop yield and yield variability in the tillage plots

Site	Year	Crop	Tillage	Yield	Coeff. of V.
				(Bu/A)	(%)
Boxall	1986	Wheat	Control	34.3 a	22
			Ripped	43.1 b	19
	1987	Wheat	Control	18.4 a	36
			Ripped	34.8 b	31
			Parapl.	29.5 b	31
	1988	Crop Failure			
McEwen	1986	Peas	Control	22.7 a	23
			Ripped	32.9 b	25
	1987	Flax	Control	21.0 a	12
			Ripped	24.0 a*	8
	1987	Flax	Control	22.5 a	12
			Parapl.	23.1 a	7
	1988	Barley	Control	30.3 a	32
			Ripped	40.8 b	30
	1988	Barley	Control	25.0 a	26
			Parapl.	37.2 b	23
Morgan	1986	Barley	Control	48.6 a	22
			Ripped	56.5 b	20
	1987	Flax	Control	23.0 a	18
			Ripped	27.1 b	10
	1988	HY320	Control	14.3 a	30
			Ripped	19.0 b	30
Rice	1988	Wheat	Control	29.1 a	25
			Ripped	33.0 a	15
Chabot	1987	Peas	Control	31.2 a	17
			Ripped	28.6 a	29
	1988	Flax	Control	9.8 a	30
			Ripped	9.8 a	25

Values that are followed by the same letter are not significantly different at the P 0.05 level

Table 8. Continued

Site	Year	Crop	Tillage	Yield	Coeff. of V.
				(Bu/A)	(%)
Cragg	1987	Wheat	Control	41.8 a	13
			Ripped	34.9 b	21
	1988	Barley	Control	23.8 a	28
			Ripped	35.4 b	12
Jessiman	1987	Wheat	Control	44.1 a	21
			Ripped	44.3 a	20
			Parapl.	46.4 a	21
	1988	Crop Failure			
Riopka	1988	Wheat	Control	21.8 a	29
			Ripped	21.9 a	29
D.Eliason	1988	Crop Failure			
J.Eliason	1988	Durum	Control	39.6 a	32
			Ripped	49.7 a*	35
Millar	1987	Flax	Control	34.7 a	13
			Parapl.	35.0 a	10
	1988	Wheat	Control	35.5 a	38
			Parapl.	37.7 a	38
Norrish	1988	Canola	Control	30.4 a	25
			Ripped	25.9 a	38
Warner	1988	Canola	Control	12.8 a	20
			Ripped	20.2 b	29

Values that are followed by the same letter are not significantly different at the P 0.05 level (ANOV of block means)

* Denotes significantly different from the "control" when analyzed as paired observations instead of ANOV of block means

In 1987, rainfall was relatively poor in the spring, and the crop in the ripped areas at Cragg's and at Chabot's was unable to fully recover, and as a consequence some of the crop never emerged and some of the crop was still quite green at the time of harvest. The same problems existed in 1988 at the Norrish site.

Deep ripping increased crop yields mainly on solonetzic soils. In the first year following deep ripping, yield increases due to deep ripping were 26 % at Boxall, 16 % at Morgan, -20% at Cragg, 26 % at J.Eliason, and 58 % at Warner. In the second year following dep ripping, yield increases were 89 % at Boxall, 18 % at Morgan, and 49 % at Cragg. In the third year following deep ripping, there was a yield increase of 33% at Morgan, while at Boxall no crop could be harvested. In the mixed solonetzic/chernozemic soils, Deep ripping improved yields only at one site, McEwen, where yield increases were 45 %, 14 %, and 35 %, in the first, in the second and in the third year, respectively, following deep ripping. At the other 3 sites (Chabot, Riopka and D.Eliason), there was no significant effect of dep ripping on crop yield. There was no significant effect of deep ripping on crop yield in any of the non-solonetzic soils (Rice, Jessiman and Norrish).

Paraplowing improved crop yield at the Boxall site (solonetzic), resulting in a 60 % increase in 1987. It also improved crop yield at McEwen (mixed solonetzic/chernozemic soil), resulting in an increase of 49 % in 1988. Paraplowing did not significantly increase crop yield at any of the non-solonetzic soils (Jessiman and Millar).

Crop yield uniformity was improved with deep ripping in the first and in the second crop year, except at the sites where poor seedbed conditions existed in the spring following the deep ripping operation. Paraplowing also improved crop yield uniformity, however, the effect lasted only into the first crop year. The above improvements to crop yield uniformity involved mainly solonetzic soils.

Crop response to strips of fertilizer nitrogen (30 and 60 kg/ha of N as 34-0-0), was negligible in terms of crop yield and in terms of nitrogen content in the harvested material. Percent protein in the harvested crop (not shown) was not significantly affected by either deep ripping or by paraplowing in any of the sampling years.

Conclusions

A total of 13 sites were included in the study involving 3 different soil zones. Based on soil chemical criteria, the sites include 5 solonetzic soils, 4 mixed solonetzic/chernozemic soils, and 4 non-solonetzic (chernozemic) soils. The deep tillage operations involved deep ripping and paraplowing, which had been carried out in the fall.

Following either deep tillage treatment, the soils tended to be less dense in the 10-50 cm depth, in the year following deep tillage. By the second year this trend had more or less disappeared. The same pattern was found in terms of soil strength.

Both deep ripping and paraplowing increased soil water recharge for up to two years following the deep tillage operation.

Crop emergence at some sites was decreased in the tillage plots, due to poor seedbed conditions, created as a result of the secondary tillage operations in spring that were required to smooth down the soil surface. In some cases poor emergence resulted in reduced yields.

Crop yield was significantly increased due to either deep ripping or paraplowing on solonetzic soils. Increases were more dramatic following deep ripping than following paraplowing. The yield increases lasted at least two years following the deep tillage operations, and at one site the yield increases lasted into the third year. Deep ripping and paraplowing increased yields on only one of the four mixed solonetzic/chernozemic soils, and in none of the 3 non-solonetzic soils. There was little effect of either deep tillage treatment on the percent protein in the crop, nor was there a significant response in terms of crop growth to different rates of nitrogen fertilizer levels.

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Shelterbelt Benefits for Soil Conservation and Crop Yields

John Kort
PFRA Shelterbelt Centre
Indian Head, Saskatchewan

Introduction

Farmers have planted field shelterbelts on the prairies to combat wind erosion for over fifty years and are currently taking advantage of conservation incentives by planting over 1000 km per year in Saskatchewan and Manitoba. The PFRA Shelterbelt Centre at Indian Head, Saskatchewan produces and distributes the necessary tree and shrub seedlings and conducts an extension program to educate farmers concerning shelterbelt benefits, assist in shelterbelt design, and advise on shelterbelt establishment, weed control and management. The Shelterbelt Studies unit conducts investigations to identify and quantify shelterbelt benefits and to develop shelterbelt design and management recommendations to support the extension program and answer farmer enquiries.

Shelterbelt Benefits for Soil Conservation

Shelterbelts are normally planted primarily to reduce wind erosion. Shelterbelt effects on wind speed are well known as many investigators have documented wind speed reduction leeward of different shelterbelt species or designs or in wind tunnels. Hagen (1976) used relative wind speed leeward of a shelterbelt to calculate soil erosion assuming that erosion was proportional to the cube of the wind speed.

Direct measurements of saltating particles leeward of two different shelterbelts in 1988 at Lipton, Saskatchewan showed that saltation increased with increasing distance from the shelterbelt to a distance of greater than 20H (Figure 1)(H is the shelterbelt height). Furthermore, measurement of various soil parameters at different distances from shelterbelts showed that soil organic matter and bulk density were higher near the shelterbelts at Conquest, Saskatchewan (Figure 2,3). The proportion of particles less than .84 mm in diameter as determined by dry sieving on a rotary sieve increased at greater distance from the shelterbelts (Figure 4). Higher organic matter may be attributed to protection of the soil in the sheltered zone. Aggregate stability is, in turn, enhanced by the higher organic matter and soil moisture adjacent to the shelterbelts. Bulk density was found to be higher near the shelterbelt possibly due to machinery compaction during the spring when soil moisture near the shelterbelt was higher from snow melt.

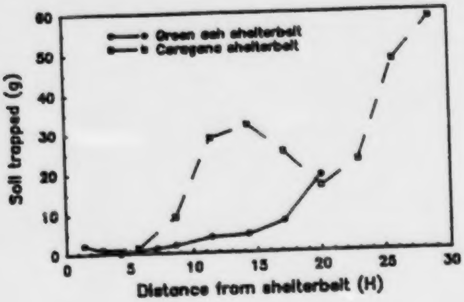

Figure 1. The effect of shelterbelts on the amount of saltating particles collected by BSNE soil samplers.

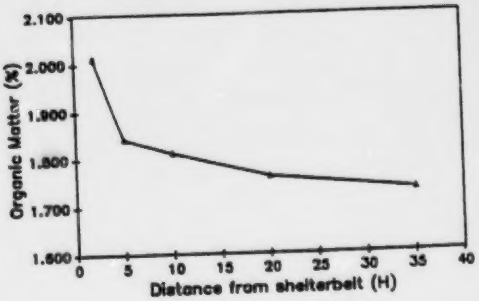

Figure 2. The effect of shelterbelts on soil organic matter in the sheltered field.

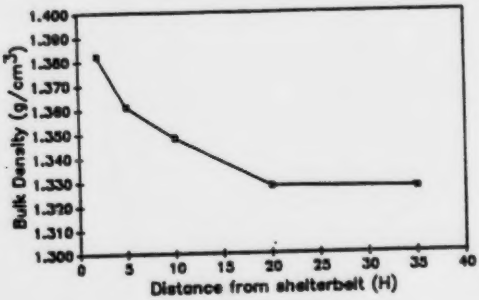

Figure 3. The effect of shelterbelts on soil bulk density in the sheltered field.

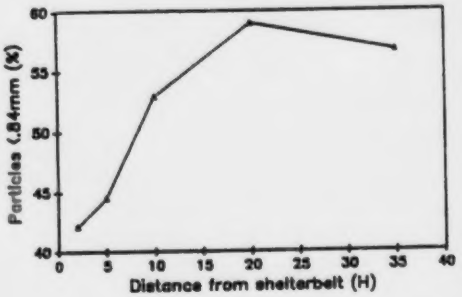

Figure 4. The effect of shelterbelts on the percent of erodible soil (<.84 mm) particles in the top 5 cm of soil in the sheltered field.

Shelterbelt Benefits for Crop Yields

Many studies conducted around the world have shown shelterbelt benefits to crop yields (Kort 1988). However, the size of the benefit depends on a variety of factors including shelterbelt species and design, climatic conditions, soil conditions and the crop grown. Reliable data for shelterbelt effects or spring wheat yield on the Prairies is available from several major studies conducted on the Prairies and the U.S. Great Plains. The combined results are expressed in Figure 5. This figure shows a loss of crop near to the shelterbelt due to the physical occupation of land by the trees and competition by the tree roots with the adjacent crop. Generally, competition extends to 1H while yields increase due to higher soil moisture, improved microclimate and physical protection of the crop. Crop yields are normally higher to a distance of 15H. Beyond 15H, crop yields return to the unsheltered level. In normal circumstances, a shelterbelt increases the crop yield by a net value of 3-5% within its sheltered zone when land occupied by the trees and competitive decreases are taken into account.

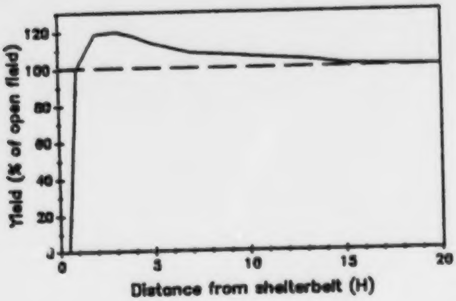

Figure 5. The effect of shelterbelts on spring wheat yield in sheltered fields.

Since the net effect on crop yield by shelterbelts depends on so many factors, a menu-driven spreadsheet was constructed in LOTUS 1-2-3 on a microcomputer to calculate net shelterbelt benefits and economic returns. The program asks the user for the shelterbelt design, orientation and distance between belts as well as for crop parameters including soil zone, crop, expected open field yield, expected crop price, and variable input costs. The spreadsheet then uses the input parameters to calculate the net yield and economic benefits throughout the life of the shelterbelt. It then creates a summary report which includes the basic assumptions made in the calculations and the overall benefits. The summary can be viewed on the screen or sent to a printer for hard copy output. An example of the spreadsheet output is shown in Table 1. It is hoped that this program will be of interest and value to agricultural extension people and producers to illustrate the economic value of shelterbelts.

Table 1. Summary report of spreadsheet calculations from user-input shelterbelt and crop parameters.

```
SUMMARY REPORT:                                      SHELTERBELT INFORMATION:
================                                     ===========================
Annual benefits of the shelterbelts at maturity      Tree SPECIES.............. GREEN ASH
    Net yield increase (%)...............     7.9                               (6ft spacing)
    Economic benefit ($).................    $399    ORIENTation................EAST-WEST
Total economic benefit over shelterbelt lifespan     Between row DISTance(ft)...     660
    In constant $$...................... $22,745     Field size(ac)(calculated).    40.0
    In present $$                                      (assumes .5 mile field length)
      (discounted at 5% per annum)......  $3,661
                                                     CROP INFORMATION:
                                                     ================
Assumptions:                                         Farm LOCATION..............BLACK SOIL ZONE
    Competition at maturity(%)..........    -3.5     CROP.......................SPRING WHEAT
    Land occupied at maturity(%)........    -2.4     Open field YIELD per acre..      30
    Yield increase at maturity(%).......    13.8     Crop PRICE($/unit).........   $3.50
    Lifespan (years)....................      75     Crop INPUT costs($/ac).....     $70
    Years to maturity...................      30
    Height at maturity(ft)..............      50
    Protective Index of shelterbelts....     0.8
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Report on the East Central Saskatchewan Soil Conservation Project

David J. Struthers
Conservation Agronomist
A.G. Kuziak Building
Yorkton, Sask.
S3N 2Y4

The East Central Saskatchewan Soil Conservation Project is a three year research and demonstration project designed to investigate:

1) the profitability of extended crop rotations
2) the value of reduced or conservation tillage

The key to this project is a three tiered field program consisting of:

1) three research sites which will examine grain and oilseed production under zero tillage, minimum tillage, and conventional tillage, using continuous cropping and a 50/50 crop fallow rotation. All crop and soil parameters are being monitored, and all inputs are being recorded so that a complete economic analysis can be made.

2) one demonstration site in each of the eight agricultural extension districts that form the region. These sites are planned in co-operation with the local agricultural representatives and district extension board. Their purpose is to illustrate a practical field scale example of soil conservation that is of interest or concern to local producers.

3) Numerous field scale examples of conservation management practices already implemented by innovative farmers in the region.

Although soil and climatic conditions in this region are suitable for extended cropping, a large number of producers still employ a 50/50 crop-fallow rotation, leading to an excessive amount of tillage. No soil conservation research has ever been conducted in this area and for this reason the project was established in this location.

This project involves three sponsoring groups:

1) Saskatchewan Agriculture:

Project demonstration sites are co-ordinated in consultation with the local agricultural extension districts. Extension activities such as tours, seminars, and field days are planned with the agricultural representatives.

2) Agriculture Canada:

Two research agronomists from the Indian Head Experimental Farm oversee the research component of the project. They assist with all field operations, data collection and analysis. Agriculture Canada has also provided the use of plot equipment and a considerable amount of shop time and labour for equipment preparation and maintenance.

3) Hoechst Canada Inc:

Hoechst has contributed technical assistance to develop and promote all levels of the field and extension programs. As well, Hoechst has provided capital funding for the purchase of research equipment and supplies.

The majority of the funding for the project is provided through the Federal-Provincial Agricultural Development Agreement, ERDA. The remainder of the funding is provided by Hoechst Canada Inc., Agriculture Division.

The project receives direction from a steering committee which is comprised of individuals from the three sponsoring groups, and four farmer members chosen from the various agriculture extension districts of East Central Saskatchewan.

Summary of Results

RESEARCH PROJECT

The research portion of this project has two objectives. The first objective is to investigate conservation tillage practices that minimize the effects of soil degradation. The second objective is to investigate extended cropping as a method of alleviating the process of soil degradation by the practice of summerfallowing. The intent is to document in as much detail as possible, how tillage systems and cropping systems affect soil water, plant growth, weed populations and control, final grain yield, and economic returns.

The practice of summerfallowing results in the accumulation of nitrate nitrogen through the process of mineralization. Given this fact, proper soil fertility and soil moisture management should alleviate the need for summerfallowing. Table 1 lists the available soil moisture to a depth of 120 cm for the various tillage and cropping systems employed at each location. In Tadmore, stubble plots had an additional 1.6 cm of moisture as compared to the fallow treatments. There was also a significant tillage system effect, with the zero till plots having the greatest levels of soil moisture. In Waldron and Ituna, there was not a significant tillage effect. However, fallowing resulted in savings of 2.2 cm of water at Waldron and 2.9 cm of water at Ituna. These amounts of moisture could also have easily been saved in a continuous cropping situation with proper snow trapping and soil water conservation techniques.

Table 1 Total available soil water (cm) in the 0-120 cm soil profile for three tillage systems and two cropping systems at three locations in East Central Saskatchewan.

Location	Tillage System	Cropping System Continuous	50/50	Mean
Tadmore	Zero	19.5	16.8	18.15
	Minimum	18.2	14.8	16.5
	Conventional	14.7	16.0	15.35
	> Mean	17.5	15.9	
Waldron	Zero	30.0	32.6	31.3
	Minimum	26.7	27.5	27.1
	Conventional	24.7	27.7	26.2
	> Mean	27.1	29.3	
Ituna	Zero	28.7	31.4	30.1
	Minimum	31.3	33.2	32.2
	Conventional	31.0	34.9	33.0
	> Mean	30.3	33.2	

Spring soil moisture conditions were better in 1988 than in 1987 for all sites. Considering 1987 yield levels and the lower soil moisture content, it is difficult to argue against extended or "flex" cropping.

One of the arguments used to justify the practice of summerfallowing is increased soil moisture content after the fallow period. It has been documented that most of the fallow recharge occurs during the first winter, and little moisture is gained the second winter. In 1988, the reverse was true. Table 2 indicates that there was a significant recharge of soil water during the second year at all three sites. Most of the gain can be attributed to excellent precipitation during the month of April, 1988. It is important to note that the levels of precipitation received during the second winter would have also resulted in a significant recharge of the continuous stubble plots. This is an excellent indicator of the potential for extended cropping rotations.

Table 2: Total soil moisture (cm) in the 0-120 cm soil profile on the fallow plots after the first and second winter of recharge for three tillage systems at three locations.

Location	System	Tillage 1987	1988	+/-
Tadmore	Zero	10.5	18.0	+7.5
	Minimum	11.6	15.5	+3.9
	Conventional	10.7	16.9	+6.2
Waldron	Zero	23.9	32.6	+8.7
	Minimum	24.2	27.5	+3.3
	Conventional	23.7	27.7	+4.4

Ituna	Zero	26.7	31.4	+4.7
	Minimum	26.9	33.2	+6.3
	Conventional	29.9	34.9	+5.0

Water use efficiency (WUE) was determined for each tillage and cropping system (Table 3). WUE was similar for the three tillage systems, but was significantly higher in the fallow versus the stubble wheat. WUE values would be much higher if we didn't include the precipitation that was received during the month of August.

Table 3: The effects of tillage and cropping system on water use efficiency (kg/ha/cm) of Katepwa at two locations in East Central Saskatchewan.

	Tillage	Cropping System		
Location	System	Continuous	50/50	Mean
Waldron	Zero	11.0	44.7	42.8
	Minimum	32.5	51.5	41.9
	Conventional	34.3	47.8	41.0
	> Mean	35.9	48.0	
Ituna	Zero	41.7	64.6	53.2
	Minimum	42.9	51.8	47.3
	Conventional	49.9	68.5	59.2
	> Mean	44.8	61.6	

Rainfall, air and soil temperatures were monitored continuously from prior to seeding until after harvest. Soil temperatures were measured at two depths, 10 cm and 40 cm, in both zero and conventional tillage plots (Table 4). Soil temperatures under zero tillage conditions were slightly cooler than at 10 cm, but no significant differences were detected.

Table 4: Average growing season atmospheric temperature (degrees C) and soil temperature (degrees C) at 10 cm and 40 cm for zero and conventional tillage treatments at three locations.

	Tillage	Soil Temperature degrees C		Atm degrees C
Location	System	10 cm	40 cm	Temp
Tadmore	Zero	19.4	16.6	17.2
	Conventional	20.2	17.1	
Waldron	Zero	16.5	14.8	16.0
	Conventional	17.9	15.2	
Ituna	Zero	16.6	15.0	19.0
	Conventional	17.6	14.3	

All treatments at each location are soil tested in the fall and fertilized according to soil test recommendations. The residual levels of NO3-N, P, K, and S were determined for each plot and means were calculated for each tillage and cropping system. The values for residual NO3-N are given in Table 5. At Tadmore, there was a significant tillage system interaction. Residual NO3-N values were highest under conventional tillage and lowest under zero tillage. Values for stubble and fallow plots were similar, indicating the low nitrogen supplying power of this soil. Both Waldron and Ituna exhibited significant tillage x cropping system interactions. Similar results were obtained in 1987.

Table 5: The effects of tillage system and cropping system on soil residual NO3-N (lbs/acre) to a depth of 60 cm at three locations.

Location	Tillage System	Cropping System Continuous	Cropping System 50/50	Mean
Tadmore	Zero	21.5	18.7	20.1
	Minimum	25.3	32.4	28.8
	Conventional	36.3	45.5	39.9
	> Mean	27.7	31.5	
Waldron	Zero	80.7	30.7	54.6
	Minimum	26.7	52.5	39.6
	Conventional	32.2	47.6	39.9
	> Mean	45.5	43.6	
Ituna	Zero	23.7	46.7	35.2
	Minimum	33.5	60.4	47.0
	Conventional	23.8	79.8	51.8
	> Mean	27.0	62.3	

At Waldron, the zero tillage stubble plots had more nitrogen than the fallow plots. The reverse was true for the minimum and conventional till plots. At Ituna, levels of N under continuous cropping were similar for all three tillage systems, but fallow N levels were significantly higher in minimum and conventional tillage systems than in zero tillage plots.

One of the major reasons producers hesitate to adopt soil conservation practices is due to the threat posed by potential changes in the weed spectrum ie) a shift towards more perennial weeds. Changes in weed populations usually translate to higher weed control costs, and more intensive management. A major objective of this project was to quantify the changes in weed populations as affected by tillage and cropping systems, and hopefully to provide some strategies to overcome the pitfalls of weed control in a conservation management system. Weed density, frequency, field uniformity, and relative abundance values have been generated for species comparison by site, tillage system, cropping sequence and crop. Further data analysis by density and relative abundance of weed types has allowed comparisons at a general level by each experimental factor.

After three years of data collection, the adoption of reduced or zero till systems has not increased the density of annual or perennial weeds, relative to a conventional tillage system. The most important consideration is the weed pressure that exists on a field prior to changing management practices. When high weed pressure exists, the costs associated with weed control may more than offset the economic benefits of soil conservation practices.

The determining factor is adopting different crop and soil management practices is economic return. One of the objectives of this project was to provide an economic analysis for the various tillage and cropping systems employed. Tables 7.1, 7.2, 7.3 provide the yields and net returns for each crop grown at each site. In 1987 fallow yields were similar to stubble yields at all three sites and all three tillage systems produced identical yields. The highest net returns were from continuous cropping, minimum tillage treatments. In 1988, results varied greatly from site to site. At Tadmore (Table 7.1), the highest returns for Katepwa and canola were from minimum or conventional till systems using continuous cropping. At Waldron (Table 7.2) the highest returns were produced on conventional till plots where a 50/50 crop-fallow rotation was employed. Zero and conventional 50/50 treatments at Ituna (Table 7.3) provided better returns than zero and conventional till continuous plots. The reverse was true for minimum till plots.

Table 7.1 The effects of tillage and cropping systems on the yield (kg/ha) and net return ($/ha) of Katepwa, HY320, and Canola at Tadmore in 1988.

Crop	Tillage System	Cropping System	Yield (Kg/ha)	Net Return ($/ha)
Katepwa	Zero	Cont.	565.8	-152.56
		50/50	629.7	-213.69
	Minimum	Cont	534.6	-95.23
		50/50	466.4	-150.64
	Conventional	Cont.	505.7	-98.32
		50/50	588.6	-128.32
HY320	Zero	Cont.	816.1	-205.87
		50/50	837.2	-178.43
	Minimum	Cont.	848.5	-189.24
		50/50	448.3	-194.45
	Conventional	Cont.	578.5	-180.64
		50/50	651.9	-171.05

Canola	Zero	Cont.	643.1	-18.45
		50/50	554.3	-79.58
	Minimum	Cont.	719.8	-43.24
		50/50	661.4	-1.92
	Conventional	Cont.	745.4	50.40
		50/50	892.9	20.40

Table 7.2 The effects of tillage and cropping systems on the yield (kg/ha) and net return ($/ha) of Katepwa, HY320, and Canola at Waldron in 1988.

Crop	Tillage System	Cropping System	Yield (Kg/ha)	Net Return ($/ha)
Katepwa	Zero	Cont.	1202.5	-54.09
		50/50	1361.9	-59.30
	Minimum	Cont.	871.8	-6.82
		50/50	1526.1	-23.08
	Conventional	Cont.	1014.8	-9.91
		50/50	1646.2	35.10
HY320	Zero	Cont.	1965.4	-16.76
		50/50	1819.0	-60.58
	Minimum	Cont.	1273.5	-30.51
		50/50	1604.1	-24.36
	Conventional	Cont.	1612.6	-19.92
		50/50	1884.2	33.82
Canola	Zero	Cont.	863.1	-39.04
		50/50	906.5	41.05
	Minimum	Cont.	530.6	-21.88
		50/50	1094.4	-77.63
	Conventional	Cont.	712.2	25.19
		50/50	1391.9	145.66

Table 7.3 The effects of tillage and cropping systems on the yield (Kg/ha) and net return ($/ha) of Katepwa, HY320, and canola at Ituna in 1988

Crop	Tillage System	Cropping System	Yield (Kg/ha)	Net Return ($/ha)
Katepwa	Zero	Cont.	961.0	-61.59
		50/50	1655.6	-36.43
	Minimum	Cont.	983.2	-19.51
		50/50	1355.2	-29.43
	Conventional	Cont.	1198.8	-22.60

		50/50	1709.7	29.40
HY320	Zero	Cont.	1022.9	-87.57
		50/50	1621.6	-62.58
	Minimum	Cont.	1232.0	-45.49
		50/50	1776.9	-55.58
	Conventional	Cont.	1156.7	-56.08
		50/50	1883.9	2.89
Canola	Zero	Cont.	843.9	48.05
		50/50	1089.1	59.46
	Minimum	Cont.	715.4	90.13
		50/50	1039.6	36.93
	Conventional	Cont.	1004.0	77.19
		50/50	1138.2	105.25

Growing conditions in 1988 affected crop yields at all three locations. Rainfall amounts were approximately 50 percent of 1987 values, and air temperatures exceeded 30 degrees C on at least 30 days at each site. The resulting heat stress more than offset the benefits of improved spring moisture conditions outlined earlier.

Demonstration Project

One demonstration project has been established in each of the eight agricultural extension districts that make up the East Central Region. These are field scale farmer co-operator sites that are planned in co-operation with the local agricultural representative and district extension board. The objectives are to illustrate some practical aspect of soil conservation in each district that is of interest or concern to local producers. 1988 is the third year of data collection from these sites.

Results from the demonstration projects are not analyzed by statistical procedures. For that reason, the material is not presented here. A summary of the results from the demonstration projects is available in the annual report.

A full copy of the Annual Report for the East Central Saskatchewan Soil Conservation Project is available by calling or writing to:

East Central Saskatchewan Soil Conservation Project
c/o David J. Struthers
A.G. Kuziak Building
72 Smith Street East
Yorkton, Saskatchewan
S3N 2Y4
Phone # (306) 786-1504

A 1988 PROGRESS REPORT ON THE SOIL AND WATER ENVIRONMENTAL ENHANCEMENT (SWEEP) AND TILLAGE 2000 (T-2000) SOIL CONSERVATION PROGRAMS IN ONTARIO.

Prepared for the Annual Meeting of the Manitoba Society of Soil Science, January 10, 1989, Winnipeg, Manitoba.

H.C. Lang, Soil and Water Management Branch, Ontario Ministry of Agriculture and Food.

ABSTRACT

Soil erosion costs Ontario farmers $68 million annually.

In 1985 the Ontario Ministry of Agriculture and Food (OMAF), Ontario Soil and Crop Improvement Association (OSCIA) and the Department of Land Resource Science, University of Guelph, initiated Tillage 2000 (T-2000), an on-farm, field sized, research demonstration project to bring "state of the art" conservation tillage systems from the research laboratory to farmers across Ontario.

Soil degradation in southern Ontario costs farmers $67 million annually.

On May 8, 1986 a five year $30 million joint Canada/Ontario initiative, the Soil and Water Environmental Enhancement Program (SWEEP), was approved with the mandate to improve soil and water quality in southwestern Ontario.

This paper will deal with the three year results of SWEEP and the 31 T-2000 farm cooperators. Highlights will include project design, soil and crop monitoring techniques, trends in yield responses and economic implications.

BACKGROUND

The effects of soil erosion in Ontario have been researched. Reports from the Pollution from Land Use Activities Reference Group (P.L.U.A.R.G.) of the International Joint Commission (1978), documented soil erosion, sediment delivery to water courses and potential phosphorus loading in the Great Lakes basin.

Annual costs of erosion were estimated by various sources. Wall and Driver, (1982) estimated the cost of erosion in crop yield, fertilizer and pesticide loss as $68 million. This increased to $75 million when the cost of drainage maintenance was included. Research by Battison and Miller (1983) reported an average 38% yield decrease when corn was grown on severely eroded soils in Waterloo Region. That amounted to $1 million loss to corn growers in one region of Ontario.

Research by Vyn and others (1983) documented the effects of no-till, the chisel plough, offset disk, ridging and other modifications to tillage equipment as alternatives to conventional tillage. Ketcheson and others (1982) reported where surface residue cover was greater than 20% after planting, soil erosion losses were reduced to an acceptable 1.8t/ha. (3 ton/ac).

Surveys by the Ontario Institute of Agrologists (1983) and Wall and others (1985) showed that soil erosion was a concern, farmers were aware of soil and water problems and many wanted to change their management practices.

At the same time the cost of on-farm and off-farm agricultural land degradation i.e. water and wind erosion and soil compaction, was studied across Canada. Fox and others (1986) reported the annual cost in yield loss due to soil compaction for corn, beans, spring grains, tobacco and vegetables in southern Ontario was $67 million. This equaled the earlier estimate of the cost of soil erosion in Ontario by Wall (1982). The Honourable H.O. Sparrow (1984) put this in perspective when he reported that soil degradation cost Canadian farmers more than $1 billion per year in farm income.

In Saskatchewan a unique and successful method of researching and demonstrating ways of maintaining soil quality and productivity was initiated by the University of Saskatchewan. It was called Innovative Acres (Farm Lab Project, Rennie and others 1983). This program utilized a comparison of paired farming systems established on 40 farm cooperator sites. Paired benchmarks were used within each farm site with the goal of bridging the gap between intensive plot scale research and field application of the developed technology. Farming systems, not specific treatments, were evaluated.

It was felt in Ontario this system of intensively monitored side-by-side demonstrations could bridge the gap between tillage plot research and field application in the farm unit. In 1985, a long-term on-farm field scale research and demonstration project was initiated by OMAF in cooperation with the OSCIA and the Department of Land Resource Science, University of Guelph. Two reports by Aspinall and others (1986, 1987) documented the progress of this program.

It was recognized as a result of reports by the International Joint Commission (1978) that phosphorus was contributing to pollution of the Great Lakes. In 1983, representatives from Canada and the United States of America signed the supplement to Annex III of the Great Lakes Water

Quality Agreement. Canada and Ontario under the 1985, Canada/Ontario Agreement Respecting Great Lakes Water Quality, established a 200 tonne per year reduction of non-point phosphorus loadings from cropland for the Lake Erie basin. Cullen and Spencer (1987) reported the results of SWEEP; a joint federal/provincial initiative announced May 8, 1986 with a mandate in southwestern Ontario over five years. T-2000 was to be included as a component of SWEEP.

SOIL AND WATER ENVIRONMENTAL ENHANCEMENT PROGRAM (SWEEP)

The Agreement

SWEEP is a five-year, $30 million joint Canada/Ontario program announced on May 8, 1986 to reduce phosphorus loadings in the Lake Erie basin. SWEEP is the agreement that implements the Canadian target of the 1983 phosphorus load reduction supplement to Annex III of the Canada/United States of America 1978 Great Lakes Water Quality Agreement to reduce phosphorus loadings from non-point sources.

This program will strive to make water clean, soils less prone to erosion and farms more productive. The program will create an awareness of the need for conservation farming practices, implement those practices and improve soil and water resources. SWEEP is targeted to all or part of 14 counties in southwestern Ontario with the objective to reduce phosphorus loadings from crop land sources, 200 tonnes per year. In comparison the United States is conducting a similar program to reduce phosphorus runoff by a total of 1700 tonnes per year.

To accomplish this, Agriculture Canada, OMAF and the Federal and Provincial Departments of Environments are working together, each with their roles and responsibilities (Table 1).

Management Committee

SWEEP is headed by a Management Committee composed of representatives from Agriculture Canada, OMAF, Environment Canada and the Ontario Ministry of the Environment. The Management Committee is responsible for the overall management of the agreement. Its purpose is to integrate and give overall direction to the federal provincial projects that constitute SWEEP. V. Spencer, OMAF and F. Cullen, Agriculture Canada co-chair this committee.

Working Committee

A Working Committee fulfills a coordinating function in SWEEP, overseeing all projects and generating reports to the

Management Committee on all activities under the agreement. The Working Committee consists of representatives of various federal and provincial agencies involved in SWEEP. G. Driver, OMAF and Rodger Thompson, Agriculture Canada co-chair this committee.

Roles

Both the federal and provincial governments have their roles spelled out in the SWEEP agreement. OMAF concentrates its efforts on providing advisory services, demonstrations and incentive grants to farmers for soil conservation as we know it today. Through their efforts, Ontario farmers are expected to expand the use of conservation farming practices on an additional 400,000 hectares (approximately 1 million acres).

Agriculture Canada on the other hand is responsible for researching existing soil conservation methods, equipment and technologies that have been developed in Canada, the United States of America or elsewhere, to see if they will work in southwestern Ontario. This research is intended to answer several questions: 1) does the technology improve water quality? 2) does it improve crop production and soil quality? and; 3) does it make economic sense for a farmer to use the technology? Any soil conservation practice or equipment that is recommended for use by farmers at the end of SWEEP must meet these three criteria.

It is the task of the federal and provincial environment departments to monitor the amount of phosphorus reduction achieved through SWEEP. They will measure changes in water quality and quantity in order to evaluate the success or failure of SWEEP.

Sub-programs

SWEEP activities are divided into seven sub-programs that are coordinated by the Working Committee. Each sub-program is under the jurisdiction of a federal or a provincial government body. Some of the sub-programs are implemented by a joint effort of two or more agencies. Together these sub-programs will contribute to SWEEP meeting its goals.

All of the projects involve a great deal of background work. During the summer and fall of 1986, OMAF and Agriculture Canada did a baseline survey of agricultural cultural practices in southwestern Ontario. 1100 farmers were asked how they farmed, what equipment they used, and what were their cropping, fertilizer, land management and pesticide herbicide programs. A similar survey will be carried out before the end of the agreement to see how the farmers have changed their farming practices as a result of SWEEP and other soil conservation programs.

Federal Sub-Programs

Agriculture Canada has allocated $15 million for testing and research in soil conservation over the term of the agreement. Three sub-programs will be implemented by the private sector under contract to the federal government. Two federal employees have been hired for this project.

The two largest projects under Agriculture Canada's jurisdiction are the pilot demonstration watershed and the technology evaluation and development projects.

Pilot Demonstration Watershed

The pilot demonstration watershed project is directed by Dr. C. Acton and Dr. G. Wall who represent Agriculture Canada on the Ontario Institute of Pedology. This program is testing the effectiveness of state-of-the-art conservation practices in action on working farms. This involves three pairs of watersheds with eight to ten farms in each watershed. Farmers in one of each pair of watersheds will use state-of-the-art conservation farming practices. Farmers in the other, or the control watershed will continue to farm as they do now. Agronomic, economic, water quality and stream flow data will be gathered from each watershed for analysis and comparison over the term of the project. This project will demonstrate the magnitude of improvement in soil and water quality that farmers can expect as a result of adopting conservation practices. This approach requires the cooperation of farmers in the paired watersheds. The budget for the pilot demonstration watershed program is $5.3 million over five years.

Beak Consultants Ltd. of Mississauga, was selected as the management contractor. Ecologistics of Waterloo is the project subcontractor. Three paired watersheds were selected in Essex, Middlesex and Elgin counties. The subcontractor is negotiating with the farmers to implement conservation technologies and has started to collect data to evaluate the impact on soils, agronomy and phosphorus reduction. Ecological Services for Planning Ltd. is responsible for a soil survey of the paired watersheds for the development of farm plans and establishing baseline soil benchmarks to monitor changes in soil.

Water Quantity and Quality Monitoring

In support of the pilot water demonstration sub-program, Environment Canada under the direction of Len Kamp of the Water

Resources Branch have designed, constructed and put in operation water quantity monitoring stations at each of the six demonstration watersheds. These monitoring stations will provide a continuous record of stream flow over the duration of the program. The Ontario Ministry of the Environment under the direction of Art Bos has instrumented six watersheds to monitor water quality and has begun to take base flow data. This information will allow the loadings of phosphorus and sediment to be calculated and compared for each watershed.

Technology Evaluation and Development (TED)

The TED project is directed by Dr. W. Findlay from Agriculture Canada's Harrow Research Station. Its mandate is to evaluate, develop and adopt cost effective technologies that will lead to soil conservation and improved soil quality. Conservation cropping, tillage, planting, and integrated pest management will be considered. TED is intended to develop and test on commercial farms, technologies that have a high probability of success. The budget for TED is $6.8 million over the term of the project.

Ecological Services for Planning Ltd., Guelph, received the contract for managing this project. The first year's activities included planning, contract negotiations, and the development of a five-year work and action plan. Capital equipment was purchased. During succeeding years, up to 50 projects will be undertaken, including: management of field variability, severe erosion, cover crops, corn hybrid selection, various equipment modifications, weed control strategies, tillage and water quality and flow, the effect of terraces on phosphorus, organic mulches and soil moisture, allelopathic effects, effective use of nitrogen fertilizer, control of problem weeds and the effect of land reshaping.

Farm Level Economic Analysis

A farm level economic analysis is part of the TED sub-program to evaluate the economic impact of newly developed SWEEP technologies and techniques. The goal of this project is to establish a data base and to develop analytical tools for a realistic economic assessment of conservation practices. This analysis will be applied to the Pilot Demonstration Watershed and the TED sub-programs.

Deloitte, Haskin and Sells, Ltd., Guelph were selected as the contractor. The contractor developed a methodology and began baseline data collection. Alternative analytical models were evaluated and selected models were implemented to correctly measure the economic benefits which are attributable to soil conservation.

The third project that Agriculture Canada is involved with consists of three parts: 1) The Technology Assessment Panel 2) The Conservation Information Centre and 3) The Socio-economic Evaluation. These projects have a total budget of $1.75 million over the term of the program.

Technology Assessment Panel (TAP)

TAP is a panel of farmers, researchers, agribusiness and government extension specialists appointed for two or three year terms by the federal Minister of Agriculture. Its mandate is to assess the suitability and practicability of technological innovations related to soil conservation. As SWEEP progresses, the panel will assess the suitability of soil conservation machinery, tillage practices and cropping methods for southwestern Ontario. The panel will provide peer group reviews of technical plans for sub-programs, projects, technical results and recommend and prioritize technology. Mr. A. Bennett is chairman of the panel and Herb Norry and Associates, London is the contractor. To date the panel organization and framework has been established, members were identified and the panel carried out the review and comment on work plans. Conservation technology from Europe and the United Sates of America were reviewed by panel members.

Conservation Information Centre

The Conservation Information Centre modelled after the Conservation Tillage Information Centre located for many years in Indiana is planned to gather information on conservation farming practices, equipment and technology and make it available to extension specialists, agribusiness and through them, to farmers and researchers. The centre is expected to act as a focal point for the exchange of information about technology and on-farm experiences with various kinds of tillage and cultural practices. It is to serve the needs of those who serve the farmers and should not duplicate services that are already provided through other agencies. A feasibility study was conducted by Ecologists Ltd. Waterloo, but to date negotiations for the establishment of the centre have not resulted in its information. Agriculture Canada proposes to fund the centre at a decreasing rate over the term of the project until the centre is self supporting.

Socio-Economic Evaluation

The Socio-Economic Evaluation Project funds research by graduate students at Ontario universities with an emphasis on the social and economic aspects of conservation farming. By studying these implications members of SWEEP should be better informed, thus enabling them to make recommendations that are effective as well as realistic. M. Hicknell replaces R. Sequin, Agriculture Canada, Guelph, as the project manager. These funds support personal service contracts with graduate students to undertake approved research that increases professional interest in conservation farming and train graduate students in the field of socio-economic soil conservation research. To date, terms, conditions and procedures for funding have been developed and circulated to universities. A review panel was established and five contracts were selected for funding.

Administration, Monitoring and Public Information

The last area of Agriculture Canada's involvement with SWEEP is a joint sub-program with the Ontario Ministry of Agriculture and Food referred to as Administration, Monitoring and Public Information. This sub-program is responsible for implementing SWEEP in a timely and efficient manner. It is charged with informing the urban and farm public of the nature and consequences of soil and water quality problems and of SWEEP's objectives. M. Hicknell, Agriculture Canada, Guelph is this project leader. The budget for this federal share is $1.15 million and the provincial share is $.25 million over the term of the project.

To date D.P.A. Group, Toronto have developed an evaluation plan for SWEEP. Work plans of all sub-programs have been approved by Management Committee. Ginty Jocius and Associates, Guelph was awarded the communication contract. The consultant worked in cooperation with OMAF to inform the producers and public about SWEEP, and its goals. Press releases, signing of projects, a display, brochures, newsletters and annual reports were produced. Tours will be carried out and a video produced to promote the cooperation and the activities that are occurring in SWEEP.

Due to delays in program implementation, federal budget reprofiling and an amendment to the SWEEP Agreement extending SWEEP to 1992-93 was approved. A five year strategy was finalized and a computerized system for project tracking was developed.

Provincial Sub-Programs

OMAF has allocated $15 million for delivering three soil conservation sub-programs over five years. The sub-programs are those which deal directly with farmers in southwestern Ontario.

Soil and Water Conservation Incentive Grants

The largest of these sub-program is the Soil and Water Conservation Incentive Grants. This sub-program is part of the Ontario Soil Conservation and Environmental Assistance Program (OSCEPAP II), headed originally by J. Arnold and presently by H. Lang, stationed at the Guelph Agriculture Centre. Its objective is to reduce phosphorus loadings by controlling the movement of water and sediment from lands that are intensively cropped. Incentives in the form of grants are available to farmers to reduce soil erosion from fields, ditches and streambanks. Farmers are reimbursed for a portion of the engineering and construction costs of soil erosion control structures. A 66% grant up to a maximum of $10,000 is provided to cover eligible costs of items such as grassed waterways, water and sediment control basins, rock chutes, drop inlets, gabion baskets, windbreaks, field tile outlet protection and seeding of buffer strips. It is hoped 1000 projects will be undertaken each year with two-thirds in the SWEEP area. During 1986, OMAF changed the program to OSCEPAP II. A new brochure was produced and the revisions increased the program's success. The budget for the soil and water conservation incentives grants is $7 million over five years.

In addition, design and planning assistance was provided by Ministry staff. Erosion Control Design courses were held to train private drainage contractors in soil and water conservation techniques. Over 100 contractors passed the courses in the last three years. These private contractors install and assist in promoting the use of soil and water conservation structures.

In 1988 the amendment to the SWEEP agreement allowed the provincial programs to include the environmental protection part of OSCEPAP II in the SWEEP area. The addition of manure structures, milk house waste treatment facilities and pesticide storages will benefit the program.

Technical Assistance

The second sub-program of OMAF is Technical Assistance. This sub-program originally lead by N. Moore and recently by H. Lang located at the Guelph Agriculture Centre, is part of the extension service of OMAF. It provides professional conservation advice using 14 soil conservation advisors and other Ministry extension and engineering specialists to encourage farmers to adopt conservation management programs. With their expertise in soils, crops, engineering and farm management, the extension specialist helps individual farmers and groups of farmers diagnose soil degradation and erosion problems on their farms and assist them in selecting conservation technology to correct these problems. These specialists organize or assist farmers to organize educational information meetings and tours, hold workshops to discuss local soil conservation problems and develop and distribute factsheets press releases, news articles and reports on conservation topics. In addition, staff cooperate with federal and provincial sub-programs aimed at developing, evaluating and demonstrating conservation technology. The budget for the Technical Assistance sub-program is $6 million over five years. In addition to these activities, conservation demonstration days are held at a local level.

On a provincial basis, cooperation with the drainage contractors resulted in a Provincial Drainage Demonstration in 1986. In 1988, 5000 farmers attended Conservation Farming '88, a very successful two-day soil conservation demonstration program held in the SWEEP area. The cooperation of many farmers, government, non-government organizations, agribusiness and universities, helped make this program a success.

Local Demonstrations

The third area of involvement of OMAF is the Local Demonstrations sub-program. This sub-program consisting of two components is lead by H. Lang located at the Guelph Agriculture Centre. This sub-program promotes the wider adoption of proven soil and crop conservation management practices, primarily conservation tillage and crop rotations. The budget for the Local Demonstrations sub-program is $1.75 million over five years. This sub-program has two components.

Side-by-Side Demonstrations

Side-by-side demonstrations, the first component consists of comparative field demonstrations of conservation farming technology. These demonstrations provide farmers with first-hand experience to implement conservation practices, monitor their benefits, potential problems, the economics of crop yields, and resulting changes in soil structure and soil degradation. Data from these demonstrations provides information on several alternative management practices. Each year over 100 side-by-side field demonstrations are established and evaluated in the SWEEP area. Many of these demonstrations are on farms of members of the OSCIA.

Tillage 2000 (T-2000)

T-2000, the second component of this sub-program, is a more intensive research demonstration project established in 1985 as a cooperative effort of OMAF, University of Guelph and OSCIA. The main objective of T-2000 is to develop and evaluate conservation farming systems for specific soil types, which maximize economic productivity and minimize soil degradation.

Project Design

The project compares conservation and conventional tillage systems on 40 farms across the province over five years. The project is long-term and includes both a research and a demonstration (extension) component within the framework of an economic farm unit. The project introduces concepts of conservation farming systems to a large number of farmers and provides a way to distribute known information and experience through field scale demonstrations.

A viable conservation farming system must consider not only the cropping program and tillage system, but also the soil resource and economic net returns. T-2000 studies the relationships among these components. Conservation tillage systems that are not meeting expectations on a project farm are modified to improve performance.

In 1985, 23 cooperators established T-2000 projects across Ontario. The following year eight more joined the program for a total of 31 study sites. In 1987 a total of 37 farmers cooperated in the project and in 1988, 43 cooperatives were involved in the program. 70 percent of the sites are in the SWEEP area.

The T-2000 project is managed by Soil Conservation Advisors, Soil and Water Management Branch, OMAF in conjunction with the Department of Land Resource Science, University of Guelph. Project teams consisting of OMAF Soil Conservation Advisors, cooperating Conservation Authority staff and farmers conduct the field work. Project data is collected by the project teams. The data is computerized and results compiled statistically by the Department of Land Resource Science, University of Guelph.

The cooperating farmers were selected on the basis of farm field site suitability (soil type, topography, access, location) and their interest and capabilities to implement conservation tillage systems.

Comparing the productivity of different tillage systems is complicated by variations in climatic conditions from year to year. The scope of T-2000 includes several years data on each cooperating farm in order to statistically evaluate the performance of all conservation tillage systems.

In addition, specific combinations of soil and topography called soil landscape units, can significantly influence crop growth and yield within a field. In 1985 one farm showed a 2.5 tonne per hectare (42 bushels per acre) variation in yield of corn between upper and lower slope positions (Figure 2).

Thus a paired sampling design was established on each field scale study site because of the interaction between tillage and soil landscape on crop yield (Figure 3). A soil survey and elevation survey is undertaken at each soil landscape unit. Each study site has two field scale treatments, a conservation and a conventional tillage system. The long axis of each plot is selected so that the major soil landscape units in the field is split (paired) by the two tillage systems. Within each major soil landscape unit, permanent paired benchmark plots are established for the collection of data from each tillage system. There are 10 to 15 benchmarks per tillage treatment. In 1987, 692 benchmarks were monitored.

At each benchmark soil and crop data is collected. Measurements include hand harvested yield, crop growth characteristics, emergence, surface residue cover, weed counts and erosion rates.

In addition, for each treatment, information regarding field history and major field operations are recorded. These include crop rotation, type and use of equipment, fuel consumption, applied herbicides and pesticides, seeding rates, dates, applied fertilizer and machine harvest yields.

At each benchmark a detailed soil survey will be completed over the term of the project. A Giddings hydraulic sampler is used to take undisturbed soil cores to a depth of one metre. The cores are sliced according to soil horizons and the samples saved for chemical and physical analyses. A grid of elevation readings around each benchmark have been taken to calculate the topograhic parameters such as slope percent and length at 20 farms.

In addition, in cooperation with TED-SWEEP projects, a subset of locations are being sampled for a naturally occurring soil tracer (137-cesium). The loss of 137-cesium over the term of the project will examine the interaction between topography, soil and tillage systems on soil erosion. At selected sites runoff collectors will be installed and rainfall simulations run to study the effect of natural and simulated rainstorms on phosphorus.

Results and Discussion

The following information represents measurements from the 1987 growing season and where appropriate a comparison to the 1986 data.

A conservation tillage system is defined as any till/plant system that leaves 20 to 30 percent crop residue cover on the soil surface following planting. For comparison purposes the different tillage systems are grouped into three categories: 1) Moldboard (inversion of the surface residue, 2) Minimum (incorporation but little inversion of residue and 3) No-till (no incorporation or inversion of residue by primary tillage). For all data presented except residue levels, the averages of paired tillage comparison i.e. moldboard versus no-till were calculated using only the sites where both tillage systems were present. Thus the average yield for no-till may be different when compared against moldboard than when it is compared against minimum tillage. The use of paired tillage systems eliminates the bias of uneven soil and climatic conditions between different sites.

Residue Cover

A summary of the distribution of residue between two corn rows in 1986 is given in Figure 4. The no-till and chisel plough (minimum) tillage treatment had less residue in the row because of the use of trash whippers on the planters. The greatest levels of residue occurred between the rows and both the no-till and chisel plough (minimum) systems meet the minimum 20 to 30 percent residue criteria of conservation tillage.

A summary of the average percent residue cover from various tillage systems and crop residues (1986 and 1987) is shown in Table 2. Minimum tillage after soybeans and cereal crops have just enough residue cover to qualify as a conservation tillage system. No-till meets the criteria in all residue types but the moldboard systems had the lowest surface residue levels.

Yield and Crop Growth

A summary of corn growth characteristics is found in Table 3. In 1987 the no-till system had two to five percent lower final plant populations and a slightly lower leaf count. Plant heights (8 to 10 leaf stage) were also significantly lower than other tillage systems. These differences in crop growth however, do not seem to be related to final yield. For example, the average no-till final grain corn yields were equal or slightly higher in 1987 (Table 4).

The average grain corn yield index (conservation yield/conventional yield x 100) in 1987 was 99.5 indicating no difference in average yield on the conservation tillage plots compared to the conventional tillage plots (Table 4). This compares to a 97 yield index in 1986. In 1987 no-till grain corn yields were slightly higher than moldboard yields; nine out of 11 sites having equal or better no-till yields. Minimum tillage yields in 1987 as in 1986 were lower than moldboard yields.

The average yield indexes for all crops (1986 and 1987 combined) are given in Table 5 for three different soil textural groupings. Fine textured soils have a significantly lower yield for the conservation tillage systems. The conservation tillage systems have equal or better yields on medium and coarse textured soils.

Economic Analysis

Although economic data was collected for all sites only grain corn provided enough comparisons for an economic analysis. The information collected included a description of the operations performed in growing and harvesting the crop including labour use, tractor and machine use, custom work and materials used, plus the harvest yield and moisture content where applicable. Total costs include all preharvest labour @ $7.00 per our, machinery, fuel harvesting, hauling and drying costs. The costs of red clover and manure when used in the tillage system were not included because some of the benefits of these practices should be assessed to their use in the rotation and livestock operation.

A summary of the analysis is given in Table 6. As indicated, total preharvest costs were $18.68 per acre less for no-till systems compared to moldboard tillage. Most of this difference is due to reduced costs for seedbed preparation. The preharvest costs of no-till is $9.32 per acre less when compared to minimum tillage systems.

The total material costs were on the average $6.99 and $1.32 per acre higher for no-till where compared to moldboard and minimum tillage systems respectively. This is due to increased herbicide costs in the form of a spring burn-down and/or late postemergent herbicide applications.

Net returns to land management and risk were $4.58 and $10.39 per acre greater for no-till systems compared to moldboard and minimum till respectively. The cost of production per bushel of grain corn was approximately $.06 less or 4% lower for no-till.

Although not indicated in Table 6, no-till systems required 0.25 hours per acre less time for preharvest activities than moldboard or minimum tillage systems. This is a 25% reduction in total preharvest hours which would result in a time saving of approximately 60 hours for a 250 acre farm planted to corn.

Weed Control

In addition to benchmark monitoring of weed pressures, additional studies were carried out by Dr. C.J. Swanton and K. Chandler, Department of Crop Science, University of Guelph. The objective of these studies is to evaluate new and registered herbicides in no-till soybeans and corn tillage systems for burn-down and residual weed control, identify incompatibilities and compare performance on specific weed problems. This will continue in following years of the project.

Nitorgen Fertilizer Use Efficiency

It is recognized that the changes in residue management and overall soil moisture regimes under conservation tillage may result in different spatial distributions of nutrients. Studies in the United States of America have shown deep placement of urea-ammonium nitrate solutions (28 % N) below the surface residue, can increase nitrogen fertilizer use efficiency under no-till systems.

Field scale on-farm T-2000 nitrogen trials, comparing injected 28% nitrogen fertilizer under no-till and conventional tillage systems were conducted on nine farms by Dr. G. Kachanoski, Department of Land Resource Science, University of Guelph. The results in Table 7 indicate that check yields (zero nitrogen fertilizer) are lower with no-till. However, no-till has a higher nitrogen use efficiency, thus the final maximum economic yield and economic nitrogen fertilizer rate are similar.

Insect and Disease Monitoring

In addition to the benchmark monitoring of insect and diseases, additional studies were carried out on T-2000 sites by K. Hough, Feed Crop Specialist, Plant Industry Branch, OMAF.

In 1986 and 1987, the levels of corn ear mold and mycotoxin contamination were evaluated. For all practical purposes the 1986 results (Table 8), indicated no differences in ear mold infection between conventional moldboard plow and reduced (chisel) or no-till systems, although conservation tillage did result in a slightly higher mold severity than conventional moldboard plowing. In 1987 there was no difference in mold levels or mycotoxin levels due to tillage at two of three sites.

CONCLUSIONS

In conclusion, the collective strengths and expertise of the agricultural and environmental government agencies at the federal and provincial levels and the cooperation of the private sector are implementing successfully the SWEEP initiatives in southwestern Ontario. Each of the seven sub-programs are achieving milestones that will ensure SWEEP meets its goals of reduced phosphorus loads in the Lake Erie basin. The innovative T-2000 sub-program is producing results that indicate conservation tillage systems can improve land productivity and profit while maintaining soil quality. T-2000 is providing linkages to the TED, TAP, Farm Level Economic Analysis and Administration, Monitoring and Public Information sub-programs. The reprofiling of federal funds and amendment to the SWEEP agreement extending the federal programs for three years, will ensure that valuable data will be collected on conservation technologies. By protecting the environment and enhancing agricultural productivity, SWEEP will play a crucial role in the future adoption of conservation tillage systems in Ontario.

TABLES AND FIGURES

ORGANIZATIONAL CHART FOR THE
SOIL AND WATER ENVIRONMENTAL ENHANCEMENT PROGRAM (SWEEP)

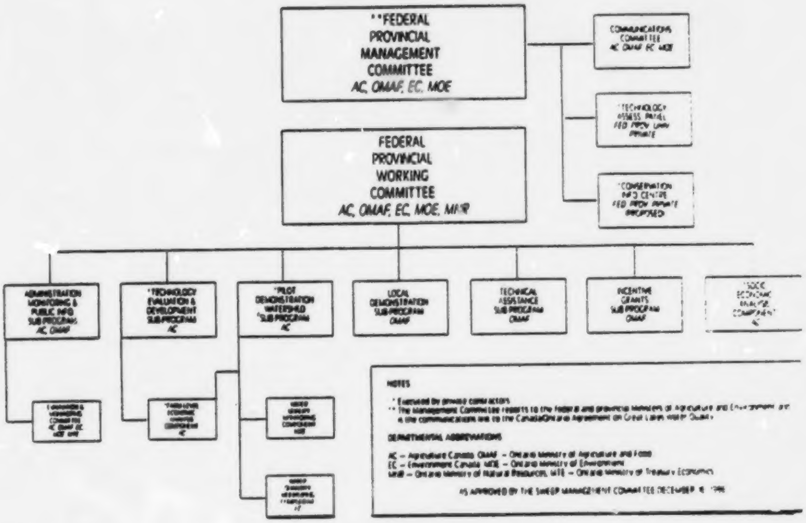
**FEDERAL PROVINCIAL MANAGEMENT COMMITTEE AC, OMAF, EC, MOE
COMMUNICATIONS COMMITTEE AC OMAF EC MOE
*TECHNOLOGY ASSESS PANEL FED PROV UNIV PRIVATE
*CONSERVATION INFO CENTRE FED PROV PRIVATE PROPOSED
FEDERAL PROVINCIAL WORKING COMMITTEE AC, OMAF, EC, MOE, MNR
ADMINISTRATION MONITORING & PUBLIC INFO SUB PROGRAM AC, OMAF
*TECHNOLOGY EVALUATION & DEVELOPMENT SUB PROGRAM AC
*PILOT DEMONSTRATION WATERSHED *SUB PROGRAM AC
LOCAL DEMONSTRATION SUB PROGRAM OMAF
TECHNICAL ASSISTANCE SUB PROGRAM OMAF
INCENTIVE GRANTS SUB PROGRAM OMAF
*SOCIO ECONOMIC ANALYSIS COMPONENT AC
NOTES
* Executed by private contractors
DEPARTMENTAL ABBREVIATIONS
AC – Agriculture Canada OMAF – Ontario Ministry of Agriculture and Food
EC – Environment Canada MOE – Ontario Ministry of Environment
MNR – Ontario Ministry of Natural Resources MTE – Ontario Ministry of Treasury Economics
AS APPROVED BY THE SWEEP MANAGEMENT COMMITTEE

Table 1. **Organizational chart for the Soil and Water Environmental Enhancement program SWEEP. Cullen and Spencer, 1987.**

CROP RESIDUE	TILLAGE SYSTEMS MOLDBOARD	MINIMUM	NO-TILL
CORN	15	34	64
SOYBEANS	6	22	48
CEREALS	4	23	69

Table 2. Average percent surface cover for different tillage systems and crop residues (1987 growing season). Aspinall and others, 1987.

PAIRED TILLAGE	FINAL POPULATION 1986	1987	LEAF* COUNT 1986	1987	PLANT** HEIGHT (cm) 1986	1987
MOLDBOARD	22895	28219	8.6	9.1	50.2	59.7
NO-TILL	21561	27622	8.2	8.4	49.6	54.3
% DIFFERENCE	-6.0	-2.0	-5.0	-8.0	-1.0	-6.0
MOLDBOARD	25274	26092	7.9	7.9	45.6	56.1
MINIMUM TILL	27438	26002	8.0	7.9	48.8	54.8
% DIFFERENCE	9.0	-0.5	1.0	0.0	-7.0	-2.5
MINIMUM TILL	24709	26879	8.5	8.3	36.1	54.0
NO-TILL	25144	25625	7.5	7.6	31.3	49.1
%DIFFERENCE	2.0	-5.0	-12.0	-8.0	-13.0	-13.0

*Average number of leaves at time of sampling (6-10 leaf stage)

**At time of leaf count.

Table 3. Summary of corn crop growth characteristics. Aspinall and others, 1987.

TILLAGE COMPARISON	CORN GRAIN YIELD (B/AC) 1986 YIELD	No. of Comparisons	1987 YIELD	No. of Comparisons
1. Moldboard	110.9		137.3	
Minimum	104.8	8	132.4	14
Index	94.0		96.0	
2. Molboard	93.5		144.2	
No-Till	85.5	3	145.9	11
Index!	91.0		101.0	
3. Minimum	118.3		137.7	
No-Till	121.3	7	136.0	10
Index	102.0		98.0	
Average Yield Index	97.0		99.5	

Table 4. Average corn grain yields (1986 and 1987) for the paired tillage comparisons. Aspinall and others, 1987.

	PAIRED TILLAGE COMPARISON		
SOIL TEXTURE	MOLDBOARD MINIMUM	MOLDBOARD NO TILL	MINIMUM NO TILL
Coarse	102	100	106
Medium	101	100	97
Fine	96	89	94

*Conservation tillage yield/conventional tillage yield x 100.

Table 5. **Yield indexes for all crops, 1986 and 1987, for three textural groupings and three tillage systems comparison. Aspinall and others, 1987.**

OPERATION/ ACTIVITY	MOLD BOARD	MIN. TILL	DIFF.	MOLD BOARD	NO TILL	DIFF.	MIN. TILL	NO TILL	DIFF
SEEDBED	19.66	15.93	3.74	23.55	1.57	21.98	14.18	2.82	11.37
SPRAY+/-APPLY FERT.	3.56	2.99	0.57	2.81	2.87	-0.66	1.71	1.92	-0.20
PLANTING	11.02	11.20	-0.18	9.49	13.10	-3.60	13.46	13.62	-0.16
SPRAYING	1.85	2.55	-0.70	1.16	1.81	-0.65	2.66	1.56	0.10
APPL N	3.87	3.87	0.00	4.47	4.53	-0.07	4.84	5.07	-0.22
OTHER	0.37	0.12	0.25	4.60	3.52	1.08	0.68	2.24	-1.56
TOTAL PREHARVEST	40.34	36.67	3.67	46.08	27.39	18.68	37.54	28.22	9.32
MATERIALS									
SEED	27.82	27.82	0.00	29.02	28.61	0.41	28.79	28.79	0.00
FERTILIZER	54.10	53.83	0.27	51.60	51.52	0.08	53.41	53.90	-0.49
HERBICIDES	27.43	27.95	-0.52	27.22	34.71	-7.48	25.69	26.52	-0.83
INSECTICIDES	2.77	2.77	0.00	0.14	0.14	0.00	1.32	1.32	0.00
TOTAL MATERIALS	112.13	112.38	-0.24	107.99	114.98	-6.99	109.21	110.53	-1.32
HARVEST									
COMBINING	21.05	21.12	-0.07	24.80	22.90	1.82	23.49	23.42	0.07
HAUL @ $6.00/TONNE	22.16	21.89	0.27	22.85	22.69	0.15	20.75	21.23	-0.48
DRYING	37.53	36.66	0.87	37.68	38.06	-0.38	30.77	31.41	-0.64
TOTAL HARVEST	80.74	79.67	1.07	85.33	83.74	1.59	75.01	76.06	-1.05
TOTAL COSTS	233.22	228.71	4.50	239.39	226.11	13.28	221.76	214.81	6.95
YIELD @ 15.5%, BU/AC	143.07	143.98	-0.91	147.43	144.53	2.90	135.34	136.48	-1.15
GROSS RETURNS	429.22	431.95	-2.73	442.29	433.59	8.70	406.01	409.45	-3.44
RETURNS TO LAND, MANAGEMENT AND RISK	196.00	203.23	-7.23	202.90	207.48	-4.58	184.25	194.64	-10.39
COST/BU	1.63	1.59	0.04	1.62	1.56	0.06	1.64	1.57	0.06

Table 6. **Economic comparison of paired tillage systems. Aspinall and others, 1987.**

Treatment	Conv.-Till	No-Till	Difference
Check yields (bu/ac)	105.2	98.0	7.2
Maximum fertilizer N use efficiency (lb grain/lb N)	22.0	33.0	-11.0
Maximum economic yield (bu/ac)	139.8	141.4	- 1.6
Maximum economic N fertilizer rate (lb. N/ac)	153.0	155.0	- 2.0

Table 7. 1986, 1987 responses of locations to injected 28% Nitrogen fertilizer. Adopted from Aspinall and others, 1987.

Site	Tillage	Incidence	Severity	Index of Incedence	Index of Severity
1	Moldboard	42	1.3	79	59
	No-Till	64	3.1	121	141
2	Disc	60	24.2	118	104
	No-Till	42	22.1	82	95
3	Moldboard	68	16.7	100	117
	Chisel	68	11.8	100	83
4	Moldboard	58	5.8	89	63
	Chisel	74	15.8	114	172
	No-Till	64	6.0	98	65

Table 8. Summary of Corn Ear Mold (Fusarium sp) survey. Aspinall and others, 1986.

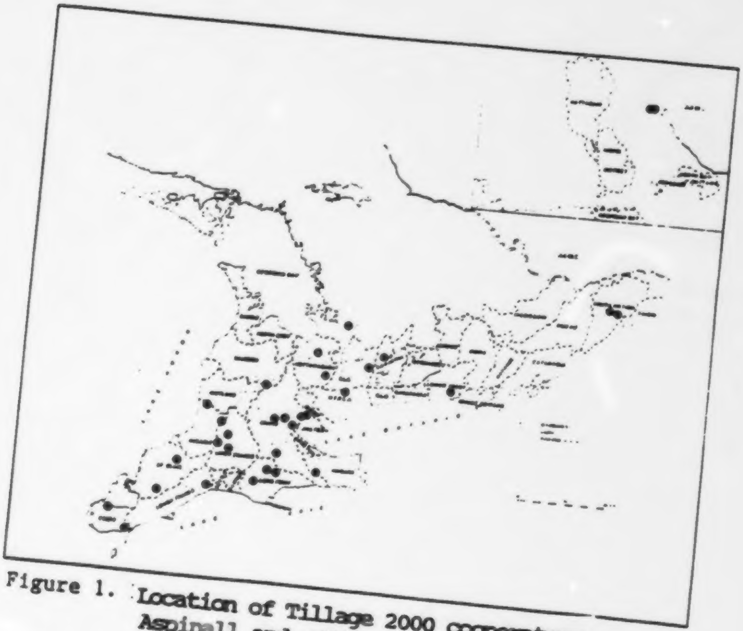

Figure 1. Location of Tillage 2000 cooperators. Aspinall and others, 1987.

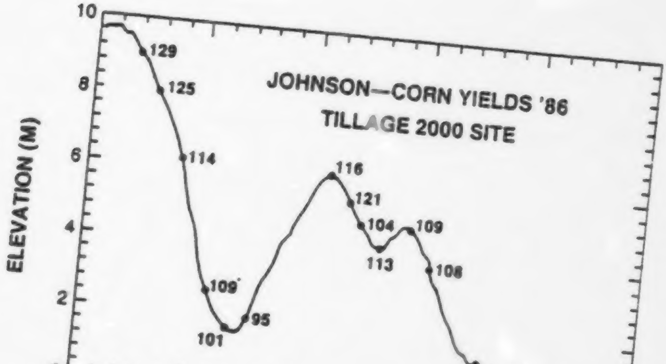

Figure 2. Effects of topography on corn grain yield (bu/ac) at a Tillage 2000 site Aspinall and others, 1986.

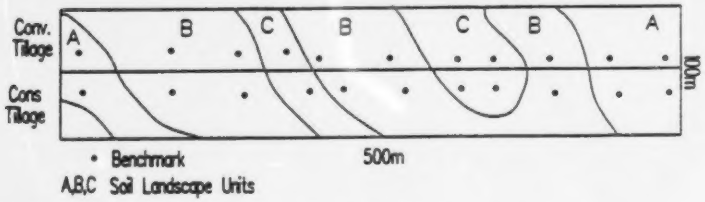
Conv. Tillage
Cons Tillage
A
B
C
B
C
B
A
100m
• Benchmark
500m
A,B,C Soil Landscape Units

Figure 3. Typical field plot design Aspinall and others, 1986.

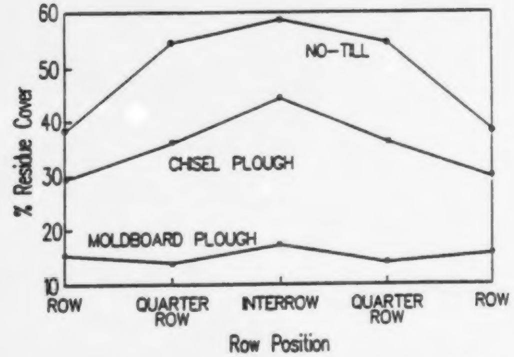

Figure 4. Distribution of percent residue cover between two corn rows for different tillage systems. Aspinall and others, 1986.

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MANITOBA AGRICULTURE SOIL CONSERVATION STRATEGY

G.C. Jenkins
Manitoba Agriculture

In response to an increased awareness and concern about the state of agricultural soils in Manitoba, a task force was set up to study the problem and to make recommendation for action to the Government of Manitoba.

The task force identified seven issues which are directly or indirectly related to conditions which threaten the sustainability of the agricultural soil base or are detrimental to the economic use of the soil.

These issues are: soil degradation caused by wind and water erosion and loss of organic matter; on-farm water management ranging from excess soil moisture caused by poor drainage to droughty conditions; inefficient use of available soil moisture caused by poor cultural practices; soil salinity; environmental pollution; inadequate land utilization and planning and inadequate conservation education.

A working group within Manitoba Agriculture was set up and charged with the responsibilities of developing a strategy for planning and delivering programs to deal with the issues identified by the task force. The strategy provides background information on the need for action; defines objectives; sets out measurable goals; and identifies a delivery mechanism.

The objectives are:

(1) To provide social and economic benefits to Manitoba by sustaining or increasing the productivity of the land base.

(2) To enhance the long-term productivity of land currently under agriculture over developing new lands.

(3) To develop an integrated working and financial arrangement amongst rural municipalities, the provincial and federal governments and non-government organizations.

(4) To minimize long-term development and maintenance costs.

(5) To reduce soil and water management constraints that cause instability and high risk.

Specific objectives were developed for each of six issues. These are:

1) Maintenance of soil quality.

    1.1) Soil erosion shall be controlled within the tolerable loss levels of 5 tons per acre or less.

    1.2) Soil organic matter shall not decline to less than 3.5% where it is currently greater than that amount and 100% of current value in soils below 3.5% organic matter.

2) On-farm soil-water management.

   2.1) Land drainage systems will provide protection to soils to a standard to service the agricultural soil capability. i.e. High class soils that produce sensitive crops will receive a higher standard of drainage than will low class soils that are used for native hay or grazing.

   2.2) Drainage networks will protect currently developed agricultural lands. In view of the greater benefit/cost ratio of providing drainage protection to existing agricultural soils and the extreme costs of developing and servicing new areas, emphasis is placed on developed areas with priority on the high class soils.

   2.3) Efficient use of available soil moisture shall be enhanced by appropriate cultural practices. It is felt that yield is often lost because inefficient and excessive tillage at critical times of the year result in loss of valuable soil moisture through evaporation.

3) Management of saline soils.

   3.1) The objective is to stop the spread of saline soil conditions and to develop and implement cultural practices which will optimize production from currently saline affected areas.

4) Environmental pollution.

   4.1) Pollution control programs will be designed so as to cause minimum disruption to established soil management practices. The major concerns are pollution of groundwater aquifers by chemicals and agricultural production by-products and the pollution of surface waters by contaminated runoff.

5) Land utilization and planning.

   5.1) To protect prime farmlands and agricultural organizations from the adverse impact of developments that may threaten continued agricultural viability.

6) Conservation education.

   6.1) To develop programs that will upgrade the level of understanding and expertise of conservation principles and practices with department staff.

   6.2) To develop and implement, in cooperation with the Department of Education and the Faculty of Agriculture conservation programs for school & university curriculum.

   6.3) To support conservation education programs with non-government agencies.

Soil conservation programs, for the most part, are funded out of regular department budgets, but supplemented by Federal Government money through various cost-share agreements such as Agro-Man and Agri-Food.

In December 1987 the Hon. John Wise, Minister, Agriculture Canada announced a $75 million, 3 year soil conservation initiative program. Some $60 million of these funds are to be used in Western Canada and matched by equal amounts of provincial dollars. Manitoba is currently negotiating for $4.5 million of federal funds and $4.5 million of provincial funds to effect a $9.0 million program.

Subsequent to this announcement a National Soil Conservation Program was established under the direction of Dr. Harry Hill (seconded from P.F.R.A.).

One of the primary activities is to develop soil and water accords between Agriculture Canada and the provinces.

The accords will enable Canada and Manitoba to implement soil and water conservation and development programs in Manitoba which meet long-term national and provincial goals; and to establish the process by which programs for soil and water conservation and development shall be established and delivered. The accords are on-going but can be cancelled by either party upon sufficient notice.

There is an agreement, supplemental to the accords which identifies what the two principle agencies will do over the course of the three year National Soil Conservation program. For example, the promotion of appropriate resource use; the enhancement of economic diversity; the increase of awareness; the demonstration and encouragement of appropriate cultural practices; technology transfer; financial programs and program administration.

A work plan further supplements the accords and details the activities that will be carried out in the implementation of the five conservation programs, - on-farm soil conservation; alternate land use; education and technology transfer; development and research and monitoring and evaluation.

ENERGY USE EFFICIENCY OF WINTER AND SPRING WHEAT IN ZERO AND CONVENTIONAL TILLAGE CROP SYSTEMS

A. O. Ridley and D. F. Kraft
Departments of Soil Science and Agricultural Economics, respectively
University of Manitoba

INTRODUCTION

Following the world oil crisis of late 1973, considerable interest was focused on the efficient use of world energy supplies. Agriculture is a large user of energy in the form of fuel oils; transportation; and machinery and agricultural chemical manufacture. Production methods that result in increased output per unit of energy input would thus make agriculture more energy efficient.

Recent innovations on the Canadian Prairies that show promise in increasing wheat yields include the production of winter wheat. This crop has greater yield potential than spring wheat because of its genetic constitution and because it is planted in the fall and can make more efficient use of early spring moisture. It also initiates growth earlier in the spring than spring wheat which may help it to avoid heat and moisture stress at critical development stages. Winter wheat, however, needs to be covered by an insulating blanket of snow during the winter to protect the plant crowns from low temperatures and winter kill. Research has shown that by planting the crop into standing stubble utilizing zero tillage planting techniques, sufficient snow is trapped to provide the necessary cover, and enhance survival.

High yields of crops, however, can only be achieved in intensive cropping systems with the use of fertilizers, particularly nitrogen. Energy expended in the manufacture of N fertilizer is high. Vigneault (1986) reported that 20.9 G_j of energy is required to produce a tonne of urea in a high technology fertilizer plant using natural gas. This is equivalent to 0.0454 G_j Kg^{-1} of N. Under intensive cropping systems where the rate of N applied is often 50 - 100 kg ha^{-1} N the energy input from N alone for crop production is a high proportion of the total.

A project was initiated by the Department of Soil Science, University of Manitoba in the fall of 1984 to determine the energy efficiency of winter and spring wheat under zero and conventional tillage. The project included an evaluation of energy requirements for the production of wheat at several rates of applied N. This report presents data for three crop years at two sites and updates data presented at the 1988 Annual Meeting of the Manitoba Society of Soil Science.

METHODS

Yield data from three crop years (1985-87) of a nitrogen rate experiment conducted on Manitou CL and Wellwood CL were used in this study of energy efficiency in crop production. Nitrogen was applied at rates of 12, 30, 60, 90, 120, 180, 240 and 300 kg

ha^{-1} N for spring wheat under zero tillage (SWZT) and winter wheat under zero tillage (WWZT). Spring wheat was also grown under conventional tillage (SWCT) however only four rates of N were applied: 12, 60, 100, 300 kg ha^{-1} N. The N was broadcast after planting using urea. All plots received 25 kg ha^{-1} P with the seed which supplied 12 kg ha^{-1} of the N received. Winter wheat (c. Norstar) and spring wheat (c. Neepawa) were planted at 100 kg ha^{-1} using a Model 2200 Versatile zero tillage hoe drill.

Energy inputs for field operations (harrowing, discing, cultivating, spraying) were obtained from data files of the Department of Agricultural Economics, University of Manitoba and Alder et al. (1976). Energy required to operate the zero tillage drill on non-worked and previously worked land was determined in a field study conducted alongside this one. Energy inputs for field operations do not include on or off field transportation, or energy for handling and storing supplies and grain.

Energy inputs for chemical manufacture included in this study were obtained from several sources:

- energy for N fertilizer manufacture was based on production of urea in a highly efficient plant using natural gas, reported by Vigeault (1986).
- energy for P fertilizer was based on estimates reported by Faidley (1977). In this study a rate of P application of 12.5 kg ha^{-1} P was assumed for energy input because in other experiments maximum crop response was obtained at this rate.
- energy for herbicide and fungicide manufacture was based on estimates by Green and McCulloch (1976) of 200 G_Jt^{-1} for 100% ai chemical. In this study the rate of application assumed was 0.5 kg ha^{-1} of 100% ai ingredient per application.

Energy for machinery manufacture was based on data of Steinhart and Steinhart (1974) reported by Hodgkinson (1975). In these estimates, the weight of the implements and weight of tractor and engine manufacture were considered. Energy inputs were amortized over a period of six years for a sprayer; fifteen years for a small tractor and combine; and ten years for all other implements. A farm size of 300 ha was assumed. Energy for machinery does not include grain storage bins, augers, tools, repairs etc. which are common to all crop systems and cannot be estimated by the authors.

RESULTS AND DISCUSSION

Yield data used in this study are calculated from regression analysis, and are means of three crop years except for WWZT at Carberry which is an average of two crops. The Carberry site (Wellwood CL) represents an area of higher daily temp. and lower growing season rainfall than the Manitou CL site (Manitou), thus crops at Carberry may be more stressed than crops at Manitou.

Energy input estimates for the manufacture of farm machinery used in this study are shown in Table 1. Energy inputs per ha for grain production are shown in Table 2, and includes estimates for field operations; chemical manufacture (except N fertilizer); and machinery manufacture. Energy inputs are highest for SWCT (2.858 G_j ha^{-1}) because of the need for a cultivator and disc and for their operation. However energy for herbicides and their application are lower for SWCT than either for WWZT or SWZT. Energy inputs per ha for WWZT and SWZT were 2.404 G_j ha^{-1} and 2.142 G_j ha^{-1} respectively. Inputs are higher for WWZT compared to SWZT because of the need for herbicide spraying in the fall and for fungicide spraying for WWZT.

Energy efficiency has been calculated as a ratio of G_j of energy input per kg of grain produced (Tables 3 and 4). Thus as the energy efficiency ratio increases, the efficiency of N use decreases. Yields of all crops increased with increasing rates of N applied up to approximately 180 kg ha^{-1} N. Increases in yield per kg of N applied were greatest at low rates and diminished up to 180 kg ha^{-1} N. Thus the efficiency of applied N was reduced with increase rates of applied N.

Crop yields were higher at Manitou than at Carberry and this reflects the generally less stressful growing conditions at Manitou. Because yields were higher, the energy used per kg grain produced was lower at Manitou than Carberry.

In general, SWZT used less energy per kg grain produced than did WWZT or SWCT. At Carberry, WWZT was the least energy efficient crop whereas at Manitou, SWCT was the least energy efficient.

In modern intensive cropping systems lack of N is often the most limiting factor for high crop yields. Thus, despite the decreasing efficiency of energy use with increasing rates of N applied, N must be used at rates required to produce high economic returns. It is common for farmers to use 60 or more kg ha^{-1} N. Comparing the cropping systems in which N was applied at 60 kg ha^{-1} the energy efficiency ratios (M_j kg^{-1}) are:

WWZT	SWCT	SWZT	SWCT	WWZT	SWZT
Carberry >	Carberry >	Carberry >	Manitou >	Manitou >	Manitou >
2.393	2.246	1.902	1.809	1.586	1.557

This ranking shows that less energy was required for grain production at Manitou than at Carberry. It also shows that at both locations SWZT was a more energy efficient cropping system than WWZT or SWCT.

CONCLUSIONS

1. High energy efficiency is dependent upon achieving high yields. In this study yields and energy use efficiency were greater at Manitou than at Carberry and reflect the less stressful growing conditions at Manitou.

2. To achieve high yields in intensive cropping systems, N fertilizer is often required. However, use of N will result in reduced energy efficiency because of the high energy inputs in fertilizer manufacture.

3. Nitrogen fertilizer represents a major portion of the energy used in crop production. Based on a 60 kg ha^{-1} rate of N, nitrogen accounts for 52% of the energy inputs for WWZT; 55% of the energy inputs for SWZT and 48% of the energy inputs for SWCT. When P fertilizer at 12.5 kg ha^{-1} P is also included, energy for fertilizer manufacture accounts for 60%, 63% and 55% of the energy input for WWZT; SWZT and SWCT respectively. Application of N at optimum rates, and by methods that will increase recovery by crops is essential in improving the energy use efficiency.

ACKNOWLEDGEMENTS

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Table 1. Energy input estimates for the manufacture of farm machinery

Equipment	Weight[1] (kg)	Energy of Mfg[2] (G_j)	Service Life (years)	Farm Size (ha)	Amortized Energy G_j ha^{-1} $year^{-1}$
Tractor (127 hp)	6696	1408.9805	10	300	.4670
Tractor (55 hp)	3125	609.8478	15	300	.1355
Cultivator (6.1 m)	1786	142.3330	10	300	.0474
Swather (6.1 m)	1696	149.5077	10	300	.0498
Combine	5357	441.2428	15	300	.0981
Harrow (18 section)	670	53.3881	10	300	.0178
Sprayer	223	17.8312	6	300	.0099
Zero tillage drill	2700	215.1685	10	300	.0717
Disc	1786	142.3330	10	300	.0474

[1] Reported by Hodgkinson (1976).

[2] Data from Steinhart and Steinhart (1975) modified by Hodgkinson (1976).

Table 2. Energy input (G_j ha^{-1} $year^{-1}$) for grain production

Operation	WWZT	SWZT	SWCT
(1) Field			
fall cultivate	---	---	0.2958
fall harrow	0.0744	0.0744	0.0744
spring disc	---	---	0.3259
spring harrow	---	---	0.0744
plant wheat	0.3170	0.3170	0.3120
spray herbicide and fungicide	0.2973 (4x)	0.1860 (2½x)	0.1488 (2x)
broadcast N	0.0650	0.0650	0.0650
(2) Chemical Manufacture			
herbicide and fungicide	0.4000 (4x)	0.2500 (2½x)	0.2000 (2x)
P fertilizer @ 12.5 kg ha^{-1} P	0.4000	0.4000	0.4000
(3) Machinery Manufacture			
tractor (127 hp)	0.4670	0.4670	0.4670
tractor (55 hp)	0.1355	0.1355	0.1355
cultivator	---	---	0.0474
disc	---	---	0.0474
harrow	0.0178	0.0178	0.0178
sprayer	0.0099	0.0099	0.0099
zero tillage drill	0.0717	0.0717	0.0717
swather	0.0498	0.0498	0.0498
combine	0.0981	0.0981	0.0981
	2.404	2.142	2.858

Table 3. Mean yields (kg ha^{-1}) and energy efficiency ratio (M_j kg^{-1}) for 3 crop years at Carberry

Rate of N applied (kg ha^{-1})	WWZT		SWZT		SWCT	
	Yield	Energy eff.	Yield	Energy eff.	Yield	Energy eff.
12	1722	1.713	2196	1.224	2003	1.699
30	1892	1.990	2397	1.462	--	--
60	2143	2.393	2696	1.902	2485	2.246
90	2347	2.765	2941	2.207	--	--
120	2503	3.137	3134	2.505	--	--
180	2674	3.955	3358	3.149	3155	3.496
240	2655	5.009	3370	3.947	--	--
300	2447	6.548	3168	5.058	3044	5.413

Table 4. Mean yields (kg ha^{-1}) and energy efficiency ratio (M_j kg^{-1}) for 3 crop years at Manitou

Rate of N applied (kg ha^{-1})	WWZT		SWZT		SWCT	
	Yield	Energy eff.	Yield	Energy eff.	Yield	Energy eff.
12	2789	1.057	2721	0.988	2713	1.254
30	2966	1.270	2889	1.213	--	--
60	3233	1.586	3139	1.557	3086	1.809
90	3457	1.877	3343	1.863	--	--
120	3636	2.160	3503	2.167	--	--
180	3863	2.738	3687	2.869	3614	3.052
240	3914	3.400	3692	3.531	--	--
300	3790	4.228	3516	4.483	3554	4.636

INFLUENCE OF SINGLE STRAINS AND A COMMERCIAL MIXTURE OF BRADYRHIZOBIUM JAPONICUM ON GROWTH, NITROGEN ACCUMULATION AND NODULATION OF TWO EARLY MATURING SOYBEAN CULTIVARS

L. D. BAILEY

Agriculture Canada, Research Station, P.O. Box 610, Brandon, Manitoba, R7A 5Z7

ABSTRACT

Seven single strains and a commercial mixture of *Bradyrhizobium japonicum* were evaluated in association with two early maturing Canadian soybean (*Glycine max* (L.) Merrill) cultivars, Maple Presto and Maple Amber. Inoculated and uninoculated plants were grown in pails outdoors. Soil temperature at 15 cm depth was monitored throughout the experiment. At the V2, V3, R2 and R4 growth stages, whole plants were removed from the pails. Nodules were counted and weighed; roots and tops were separated, weighed and analyzed for total nitrogen. *B. Japonicum* strains 61A148, 61A196, 61A194 and 61A155 were similar in effectiveness, but superior to strains 61A124a, 61A118b, 61A101c and the commercial mixture in earliness of nodule formation, number and weight of nodules per plant, and in promoting greater root and top growth and plant nitrogen accumulation. There were indications that soil temperature may have affected nodulation.

Maple Amber showed the greater potential for symbiotic nitrogen fixation. This cultivar supported earlier nodulation, had a greater number of nodules, accumulated more nitrogen in the tops and roots and had greater growth than Maple Presto.

INTRODUCTION

The development of early maturing, photoperiod insensitive Canadian cultivars of soybean has extended soybean production into the cool, short growing season region of the Canadian prairies. The late maturing soybean cultivars grown in the United States of America (USA) and in the established soybean growing regions of the world are capable of meeting much of their nitrogen requirements from symbiotic nitrogen fixation (Patterson and La Rue 1983; Boddey at al. 1984), and it is of economic importance that they do so. However, both nodulation and symbiotic nitrogen fixation are known to be very sensitive to conditions in the root environment, in particular temperature (Matthews and Hayes 1982; Weber and Miller 1972) and availability of the appropriate Rhizobium strains (Vincent 1974; Rennie and Dubetz 1983).

In the soils of the Canadian prairies, root zone temperatures are low during the early plant growth period (Mills et al. 1977) and may be a limiting factor on plant growth and development. Wallace (1957) found that for soybean, in the U.S.A., a root temperature (RT) of 22 to 32 °C was optimum for growth and that an increase of RT from 14 °C to RT 26 °C doubled vegetative growth (Wallace et al. 1969). Matthews and Hayes (1982) reported that in Great Britian, low RT restricted the growth of inoculated and non-inoculated soybean, but the inoculated plants were much more affected. At RT of 10 °C the plants did not nodulate, however, both nodulation and nitrogen fixation increased greatly in the RT range of 15 - 25 °C.

Unlike the soils of the traditional soybean growing regions of southern Ontario and the U.S.A., which contain high numbers of Bradyrhizobium japonicum, Abel and Erdman 1964; Johnson et al. 1965; Caldwell and Vest 1970; Ham et al.

1971; Semu et al. 1979), Canadian prairie soils do not contain indigenous B. japonicum (Rennie et al. 1982). Consequently, proper inoculation is required for efficient soybean production (Bailey 1981; Rennie et al. 1982).

Soybean inoculants available to Canadian prairie farmers are multistrain preparations imported from the U.S.A. and may not be adapted to the early maturing Canadian soybean cultivars, (b) determine whether there were specific strain x cultivar interactions, and (c) determine the effect of single strains and a commercial mixture inoculant on growth and development, and nitrogen accumulation in soybean top and roots.

MATERIALS AND METHODS

Soil was collected from the 0 - 15 cm depth of a Chernozemic Orthic Black calcareous till soil with a clay loam texture (Table 1). The soil was never cropped to soybean nor inoculated with B. japonicum. Consequently, it was assumed to be free of B. japonicum strains (Rennie et al. 1982). The soil was air dried and sieved to remove undecomposed crop residue and stones. Equal quantity of soil was placed in 22 cm diameter plastic pails that were 20 cm deep. The pails were buried to within 6 cm of their tops in a field.

Two Canadian developed soybean cultivars were used in the study, Maple Presto and Maple Amber. Inoculants used in the study were granular formulations obtained from Nitragin Co., Milwaukee, WI, U.S.A. Individual inoculants contained from 2.57 to 3.39×10^8 B. japonicum g^{-1} peat as determined by most probable number analysis. Seven single strains, Nitragin Co. codes 61A101c, 61A118b, 61A124a, 61A148, 61A155, 61A194 and 61A196, a Nitragin Co. commercial inoculant containing four strains (61A101c, 61A118b, 61A124a, 61A148), and an uninoculated control were evaluated on the two soybean cultivars. The inoculants were placed in direct contact with the soybean seeds at the rate equivalent to 25 kg ha^{-1}. Sterilized peat granules were used for the control at 25 kg ha^{-1}. Six soybean seeds were placed in each pot and at emergence the number of plants was reduced to three per pot. Soil temperature was measured potentiometrically at the 15 cm depth using soil implanted thermocouples. Soybean tops and roots were harvested at the following growth stages: 1st trifoliolate (V2), 2nd trifoliolate (V3), flowering (R2), and podding (R4). At each growth stage, three pots were harvested per treatment and the number of nodules present were counted. At the V3 and R4 stages, the total weight of nodules per plant was recorded. Root and top weight per plant was recorded after air drying for 36 h at 80 °C. Dried plant material was ground to pass a 2 mm sieve in preparation for total N analysis by automated analysis on a H_2SO_4 - H_2O_2 digest (O'Neill and Webb 1970).

A three replicate split-plot design was used; main plots were two soybean cultivars and sub-plots were a control and eight inoculants. Data were analyzed for each growth stage. Statistical significance between treatment means was determined by Tukey's procedure (Steel and Torrie 1960).

RESULTS AND DISCUSSION

Soil temperature increased from 5 °C (May 1st) to a maximum of 24 °C (July, 18th), then decreased to 15 °C by September, 13th (Figure 1). This cycling of soil temperature and the measured range is normal for the soils of the eastern Canadian prairies (Bailey 1981, Mills et al. 1977). Seeding occurred on May, 30th and for the first 10 d, up to the 1st trifoliolate (V2), soil temperature was less than 18 °C. This represents the lower range of soil temperature for soybean vegetative growth (Wallace et al. 1969) and the marginal temperature required for nodulation and dinitrogen fixation (Matthews and Hayes, 1982). Soil temperature from the V2 stage to the 3rd trifoliolate (V3) and to flowering (R2) ranged from 18 °C to 25 °C, the mid-range of temperature reported by Wallace et al. (1969) for optimum vegetative growth, and by Matthews and Hayes (1982) as adequate for nodulation and dinitrogen fixation. By podding, soil temperature had decreased to 23 °C, still within the temperature range required for effective nodulation.

Cultivar Effect: Maple Amber vs Maple Presto

The uninoculated plants had no nodules (Table 2). At all growth stages and for all inoculants, Maple Amber supported more nodules, both in number and weight, than Maple Presto, particularly during the early growth stages, V2 and V3. This cultivar effect could have been caused by Maple Amber having a greater genetic potential for growth than Maple Presto, and the possibility that Maple Amber was unable to provide the bacteria with an adequate quantity of metabolites. The developmental stages of both cultivars were achieved at the same time in this experiment (Figure 1). However, at all growth stages, Maple Amber had more shoot and root dry matter and accumulated more nitrogen than Maple Presto. This would indicate that Maple Amber had the greater potential for supporting symbiotic N_2-fixation with Bradyrhizobium strains. Rennie and Dubetz (1983) also arrived at a similar conclusion in studies designed to assess the N_2-fixing potential of Groups 00 and 000 soybeans.

Bradyrhizobium Strains Effect: Nodulation and Nodule Weight

Except for strains 61A155 and 61A194, the number and weight of nodules per plant increased with advancing growth stages and increasing soil temperature (Table 3, Figure 1). For these two bacterial strains, after an initial increase in number of nodules from the V2 to the V3 growth stage, there were no further increases in number and weight of nodules per plant. It is probable that soil temperature above 20 °C may have restricted the nodulating activity of these two strains. Bacterial strains 61A148, 61A196, 61A194 and 61A155 were the more prolific nodulators. Strains 61A148, 61A196 and 61A194 were the best nodulators at the V2 growth stage. The nodulating activity of strain 61A155 was low a the V2 growth stage, but was at its maximum at the V3 stage indicating that the nodulating activity of this strain maybe restricted by low soil temperature and/or low supply of plant metabolites. Strain 61A148 and 61A196 had good nodulating activity at all growth stages.

At the V2 to V3 growth stages, when soil temperature was low (Figure 1), bacterial strains 61A124a, 61A118b, 61A101c and the commercial mixture were poor nodulators (Table 3). However, with increasing plant development and soil temperature, their nodulating activity improved and by the R4 growth stage there were only small differences or no differences between their nodulating activity (i.e. nodule numbers) and those of the other bacterial strains. These strains also produced the heavier nodules.

Bradyrhizobium Strains Effect: Shoot Growth and N Content

Dry matter and nitrogen accumulation by plants within all treatments increased over the growing period (Table 4). However, for both variables, the quantities accumulated varied significantly with treatment, but the inoculated plants were superior to the uninoculated control. Plants inoculated with Bradyrhizobium strains 61A148, 61A155, 61A196 and 61A194 were similar to each other but superior to the other plants in dry matter accumulation at all growth stages, and in total nitrogen accumulation at the R2 and R4 growth stages. However, for strain 61A155 the low level of nodulation at the V2 growth stage (Table 3), corresponded also with low accumulation of dry matter (Table 4). Similarly, the low nodulating activity of strains 61A124a, 61A118b, 61A101c and the commercial mixture (Table 3) corresponded to lower accumulation of plant dry matter and total nitrogen than that of the other strains (Table 4). It appears therefore, that the Bradyrhizobium strains affected plant growth, accumulation of plant dry mater and total nitrogen content. Neves et al. (1985) and Matthews and Hayes (1982) reported increased N_2-fixation and plant growth with increased nodulation of soybeans.

Bradyrhizobium Strains Effect: Root Growth and N Content

Root growth and N accumulation of the Bradyrhizobium inoculated plants were superior to those of the uninoculated plants (Table 5). Accumulation of root dry matter and total nitrogen increased over the growing period. Plants inoculated with Bradyrhizobium strains 61A148, 61A155, 61A196 and 61A194 had similar accumulation of root dry matter (root growth) with equivalent nitrogen accumulation. All plants inoculated with these four strains had significantly greater root growth and nitrogen accumulation than plants inoculated with strains 61A124a, 61A118b, 61A101c and the commercial mixture. There were no significant differences in root growth and nitrogen accumulation among the plants inoculated with this latter group of Bradyrhizobium strains except at the R4 growth stage.

Root growth and accumulation of root total nitrogen, as was observed for shoot growth and accumulation of nitrogen, was related to nodulating activity of the Bradyrhizobium strains and soybean cultivar, and may have been influenced by soil temperature and genetic factors associated with both strains and soybean cultivar.

Although, the commercial mixture contained Bradyrhizobium strain 61A148, the performance of this inoculant was inferior to the pure strain inoculant and similar to that of the other three pure strains comprising the mixture (strains 61A101c, 61A118b and 61A124a) (Tables 3, 4 and 5). It would appear therefore, that the presence of other strain(s) in the mixture had a negative effect on 61A148. Rennie and Dubetz (1983) reported no apparent detrimental interstrain competition for this inoculant mixture in their studies. This difference in results may be the result of warmer soil temperature and longer growing season of southern Alberta and experienced in the studies by Rennie and Dubetz (1983) as compared to this study.

In conclusion, the data clearly indicate the superiority of Bradyrhizobium strains 61A148, 61A155, 61A196 and 61A194 over strains 61A124a, 61A118b, 61A101c and the commercial mixture. While all of the strains in the first group performed well with both soybean cultivars, from this study it is impossible to predict whether mixtures of these strains among themselves or with the low performing strains will be good performers. The negative effect of interstrain competition can only be detected from evaluation tests of prepared mixtures.

However, continued testing and evaluation of single strains are necessary to identify those that are capable of performing in the cool and short growing season of the Canadian prairies.

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Table 1. Some physical and chemical characteristics of the soil used in the study

A. Pedologic Description

Soil Unit	Soil Order	Soil sub-group	Materials and Texture
Carroll	Chernozemic	Orthic Black	Calcareous clay loam

B. Chemical Description:

Depth	Organic C	NO_3-N	$NaHCO_3$-P	NH_4oAc-K	SO_4-S	pH	Cond.
(cm)	-------------------------		mg kg^{-1}	-------------------------			(dSm^{-1})
0-15	62700	17	23	910	25	7.2	1.25

Table 2. Effect of *B. japonicum* inoculation on nodulation and N composition of two early maturing Canadian soybean cultivars at four growth stages

Soybean Cultivars	Inoculation Treatment	Growth Stages				Growth Stages			
		V2	V3	R2	R4	V2	V3	R2	R4
		Number of nodules plant^{-1}				Nodule weight g plant^{-1}			
Maple Presto	No Inoculant	0	0	0	0	0	0	0	0
	Inoculant*	7 b	10 b	17 b	21 b	-	0.13 b	-	0.27 b
Maple Amber	No Inoculant	0	0	0	0	0	0	0	0
	Inoculant	10 a	17 a	20 a	29 a	-	0.18 a	-	0.50 a
		Shoot weight g plant^{-1}				Shoot nitrogen content g plant^{-1}			
Maple Presto	No Inoculant	0.40 b	0.64 c	0.86 d	4.11 d	0.02 a	0.02 a	0.03 a	0.07 d
	Inoculant	0.48 b	0.84 b	1.15 c	5.26 b	0.02 a	0.03 a	0.04 a	0.14 b
Maple Amber	No Inoculant	0.58 a	0.84 b	1.21 b	4.86 c	0.03 a	0.03 a	0.04 a	0.09 c
	Inoculant	0.59 a	0.95 a	1.30 a	6.19 a	0.03 a	0.04 a	0.05 a	0.17 a
		Root weight g plant^{-1}				Root nitrogen content g plant^{-1}			
Maple Presto	No Inoculant	0.06 b	0.14 c	0.20 c	0.63 d	0.002 a	0.002 b	0.003 c	0.006 c
	Inoculant	0.07ab	0.18 b	0.23 b	0.95 b	0.002 a	0.003ab	0.005 b	0.016 b
Maple Amber	No Inoculant	0.08 a	0.21ab	0.24 b	0.80 c	0.002 a	0.004 a	0.004bc	0.007 c
	Inoculant	0.09 a	0.22 a	0.33 a	1.11 a	0.003 a	0.005 a	0.007 a	0.018 a

* Mean of 8 inoculation treatments.
Values in a column followed by the same letter are not significantly different at $P \leq 0.05$.

Table 3. Mean effect of *Bradyrhizobium* inoculants on number and weight of nodules averaged over two early mauturing Canadian soybean cultivars at four growth stages

Inoculants	Number of nodules plant^{-1} Growth stages				Nodule weight g plant^{-1} Growth stages			
	V2	V3	R2	R4	V2	V3	R2	R4
None	0	0	0	0	0	0	0	0
Comm. mixture	2 d	4 d	14 c	20 b	-	0.08 c	-	0.33 c
61A101c	1 d	7 cd	13 c	24 b	-	0.09 c	-	0.40 b
61A118b	2 d	3 d	13 c	20 b	-	0.06 c	-	0.35 c
61A124a	5 c	10 c	18 b	24 b	-	0.07 c	-	0.46 a
61A148	16 a	19 b	22 a	31 a	-	0.19 b	-	0.48 a
61A155	9 b	24 a	24 a	25 b[+]	-	0.23 a	-	0.27 d
61A194	16 a	24 a	23 a	23 b	-	0.22 a	-	0.23 d
61A196	14 a	16 b	18 b	29 a	-	0.22 a	-	0.42ab

Values in a column followed by the same letter are not significantly different at $P \leq 0.05$, non-inoculated treatment was excluded.

[+] Values in a row connected by a line are not significantly different at $P \leq 0.05$.

Table 4. Mean effect of *Bradyrhizobium* inoculants on shoot dry matter yield and N accumulation averaged over two early maturing Canadian soybean cultivars at four growth stages

Inoculants	Shoot weight g $plant^{-1}$ Growth stages				Shoot total N g $plant^{-1}$ Growth stages			
	V2	V3	R2	R4	V2	V3	R2	R4
None	0.49 b	0.74 b	1.03 b	4.48 c	0.02 a	0.03ab	0.03 b	0.08 d
Comm. mixture	0.50 b	0.83 b	1.20 b	5.53 b	0.02 a	0.03ab	0.04ab	0.13 c
61A101c	0.46 b	0.77 b	1.06 b	5.07 b	0.02 a	0.03ab	0.03 b	0.13 c
61A118b	0.47 b	0.70 b	1.01 b	5.11 b	0.02 a	0.02 b	0.03 b	0.12 c
61A124a	0.43 b	0.78 b	1.10 b	5.34 b	0.02 a	0.03ab	0.03 b	0.15 b
61A148	0.64 a	1.03 a	1.39 a	6.17 a	0.03 a	0.04 a	0.05 a	0.17 a
61A155	0.49 b	1.00 a	1.35 a	6.15 a	0.02 a	0.03ab	0.04ab	0.18 a
61A194	0.63 a	1.08 a	1.43 a	6.00 a	0.03 a	0.04 a	0.05 a	0.16 a
61A196	0.65 a	1.01 a	1.34 a	6.75 a	0.03 a	0.04 a	0.05 a	0.18 a

Values in a column followed by the same letter are not significantly different at $P \leq 0.05$.

Table 5. Main effect of *Bradyrhizobium* inoculants on root dry matter yield and N accumulation averaged over two early maturing soybean cultivars at four growth stages

Inoculants	Root weight g $plant^{-1}$ Growth stages				Root total N g $plant^{-1}$ Growth stages			
	V2	V3	R2	R4	V2	V3	R2	R4
None	0.02 a	0.03 b	0.03 c	0.08 d	0.002 a	0.003 b	0.004 b	0.007 d
Comm. mixture	0.02 a	0.03 b	0.04 b	0.13 b	0.002 a	0.004 b	0.005ab	0.015 b
61A101c	0.02 a	0.03 b	0.04 b	0.13 b	0.003 a	0.003 b	0.004 b	0.013 c
61A118b	0.02 a	0.02 b	0.03 c	0.12 c	0.002 a	0.003 b	0.004 b	0.013 c
61A124a	0.02 a	0.03 b	0.04 b	0.11 c	0.002 a	0.002 b	0.004 b	0.017ab
61A148	0.03 a	0.04 a	0.05 a	0.17 a	0.002 a	0.006 a	0.006 a	0.020 a
61A155	0.02 a	0.04 a	0.05 a	0.17 a	0.002 a	0.005 a	0.006 a	0.020 a
61A194	0.03 a	0.04 a	0.05 a	0.16 a	0.002 a	0.006 a	0.007 a	0.017ab
61A196	0.03 a	0.04 a	0.05 a	0.17 a	0.003 a	0.005 a	0.006 a	0.021 a

Values in a column followed by the same letter are not significantly different at $P \leq 0.05$.

Utilization of N in Plant Residues by Wheat

M. Rajotte and C.M. Cho
Dept. of Soil Science
Univ. of Manitoba

In order to quantitatively determine the availability of above ground portion of plant residue to subsequent crop, to compare its availability index to commercial fertilizer and to observe the residual effect of straw and urea N under different tillage practices, a field experiment was carried out. Very highly N-15 enriched wheat straws of different C:N ratios obtained by raising wheat in a growth chamber were used.

A field experiment was initiated in 1986 on an Almasippi sand using wheat as a test crop. A small scale lysimeter made of 250 mm diameter plastic tube, 350 mm long was used in this investigation. Split plot design of tillage practice, zero vs. conventional cultivations, and combinations of commercial fertilizer and crop residue treatment was chosen. Two rates of urea at 50 kg N/ha and 100 kg N//ha and fresh wheat straw at the rate of 150 kg N/ha (5 t/ha, C:N = 17) were combined so that one source of nitrogen was labelled with N-15. In addition, labelled urea was used without wheat straw in order to estimate the availability of urea N. The urea was injected to a depth of 50 mm and the wheat straw was mixed with surface soil. Treatment details are shown in Table 1. Two harvestings of the above ground portion of wheat were carried out. The first harvest at 54 days after planting (heading) and the final harvest at 103 days after planting.

The second year wheat was grown on the same lysimeters in 1987 in order to determine the residual effect of 1986-applied fertilizers upon the second year wheat at maturity. No additional N fertilizer was applied in 1987.

An identical experiment was repeated in 1987 as was done in 1986 with different wheat straw. The N-15 labelled straw used in 1987 had C:N ratio of 48 and the amount of N applied was 60 Kg/ha at the same rate of straw addition (5t/ha). Similar times of harvest were carried out for the 1987 experment. There were 3 replicates in all the harvestings.

The yields of wheat, % N and % N-15 on all samples were determined so that the fraction of labelled N in wheat N, expressed as %NDFS (% N derived from source) and the average percent utilization of the applied N as urea and wheat straw by wheat grown on the Almasippi sand could be calculated.

Results

Final dry matter yields of wheat of 1986 treatment harvested in the first year (1986-f) and second year (1987-s), and the final yield of 1987 treatment (1987-f) are shown in Table 2. In both cases (1986-f and 1987-f), the addition of urea to the sand in the first year increased the yields of wheat. Howewer, there was no residual effect of the applied N over the next year (1987-s).

The fraction of plant N that was derived from the labelled source applied in the spring of 1986, at different times of harvest under two tillage systems are shown in Table 3. About 20 - 40 % of the total N in wheat was derived from applied urea at the first harvest. The fraction was greater with the higher rate of urea application. The values were, however, not dependent upon the addition of the wheat straw. It seems that under the conventional tillage system, the addition of the non-labelled organic matter decreased the fraction of urea-derived N in the wheat N even though it is not significant at the 5 % level. In other words, the wheat straw has supplied nitrogen so that the urea N was diluted by the N from the crop residue. This fact is seen from the values of straw-derived N in wheat when labelled straw was used. The values of %NDFS in wheat from labelled straw was greater under the conventional tillage system than from zero till system.

The values of %NDFS decreased as the wheat matured indicating that the native soil N was the main source of N during the later stages of growth. Evidently the inorganic and organic N at the given rates of application could not supply N continuously to the wheat.

The 1987 wheat grown in the lysimeters fertilized in 1986 absorbed very little N-15 from the urea plots irrespective of the amount of urea applied. There was virtually no residual effect of urea in the Almassipi sand at the rate up to 100 Kg/ha. On the other hand, the %NDFS values from labelled straw indicated that there was a residual effect of wheat straw N. Approximately 6 % of N in the second year wheat originated from straw N applied in 1986.

Virtually identical results were obtained in 1987 with urea application (Table 4). Approximately 20 - 40 % of the N in the wheat N was derived from urea N in the first harvest. The values decreased as the wheat matured indicating that the wheat utilized N mostly from the unlabelled native source as the urea source became unavailable. Causes of this unavailability are not known.

The C:N ratio of the labelled straw was 48 as opposed to 17 for the 1986 sample. The values of %NDFS for 1986-1 were nearly 20 % (Table 3) as opposed to the values of around 2 - 3 % for 1987-1 (Table 4). The values for 1986-2 (final harvest of 1986) were around 10 % as opposed to around 2 % for 1987-2 (final harvest of 1987). The values of %NDFS of residual straw (Table 3, 1987) which were obtained in 1987, the same year the results of Table 4 were obtained, were higher than the values obtained using straw of high C:N ratio. Consequently, it can be concluded that the N of straw with high C:N ratio was less available to the wheat in the first year of application.

Approximately 20 % of the applied urea N was utilized by the wheat when no straw was added (Table 5). The utilization was greater with higher rate of urea application. There seems to be no difference between zero and conventional till treatments. There was virtually no difference in the magnitude of the utilization of urea N between the two harvest dates (1986-1 and 1986-2). This indicates that the urea N was simply not taken up by the wheat after the first harvest (54 days). On the other hand, the N from the wheat straw seemed to be utilized during the same period since % utilization of N increased during this time. The utilization of straw nitrogen by wheat was about 7 to 9 % of the added N when the C:N ratio was 17, and was approximately one third of the value obtained for urea. Virtual absence of residual effect of urea applied in 1986 and evidence of the utilization of straw N applied in the previous year are clearly shown in the last two columns of Table 5.

The results obtained in 1987 (Table 6) indicates that a similar trend exists for urea as was observed in 1986 (Table 5). It seems that urea applied to the soil at the time of planting was available to wheat only at the early stages of growth in Almassipi sand. The magnitude of the urea N utilization was around 20 - 25 % and these figures are definitely lower than those previously observed in non-sandy soils. It is not known what happened to the remaining urea N. However, it can be speculated that the sandy texture, pH and high ground water table would have affected the availability of urea N. The % utilization of straw N with high C:N (48) was very small and amounted to 2 - 4 %. These values are definitely smaller than those obtained with wheat straw of low C:N (17) ratio.

Conclusion :

When there was no wheat straw applied, the utilization of urea was nearly the same between conventional and minimal tillage systems in Almasippi sand. Generally, a higher fraction was utilized by wheat if a higher rate of urea was applied. If wheat straw was applied, the degree of utilization of urea was decreased under the conventional tillage system at the early growth stage. This was accompanied by the higher utilization of the residue N under the conventional tillage system. However, the effect of tillage system upon the availability of organic N seemed to disappear as the season progressed.

Approximately 25 % of the harvested wheat N was derived from the straw N which was applied at the rate of 5 t/ha in Almasippi sand in the field thus making the fresh wheat straw a valuable source of N for the subsequent crop if the straw was harvested early so that the C:N ratio was small. When straw was harvested at maturity so that it had a high C:N ratio, the utilization of straw N to growing wheat was low.

Urea applied at the time of planting was found to be available to wheat at the early stages of growth. Virtually no urea N was utilized after the first harvest (54 th day). Consequently there was no residual effect of urea N for the subsequent crop. However, the straw applied at the rate of 5 t/ha was capable of supplying N to the second year crop. The efficiency of the second year was around 1/2 to 1/3 of the first year values.

Table 1. Experimental Soil and Treatments

Soil : Almassipi Sand, pH 7.5, OM 3.9 %
Tillage : Zero vs. Conv.

Urea (kgN/ha)	1986 Straw (kgN/ha)	1987 Straw (kgN/ha)
0	0	0
50*	0	0
100*	0	0
0	150	60
50*	150	60
100*	150	60
0	150*	60*
50	150*	60*
100	150*	60*

*labelled with N-15, straw rate = 5 t/ha
C:N = 17 (1986), C:N = 48 (1987)

Table 2. Yield of Wheat (g/lysimeter)

Treat.	1986-f	1987-s	1987-f
0 - 0	20.5 a	21.4 a	18.7 ab
50*- 0	31.3 bc	26.5 ab	25.9 cd
100*- 0	40.2 d	22.6 a	33.8 e
0 - S*	30.5 b	22.0 a	16.6 a
50 - S*	35.9 c	30.7 b	23.3 bc
100 - S*	41.4 d	21.4 a	30.2 de

S* = 150 or 60 Kg/ha
f = first year of the treatment.
s = second year of the previous treatment.

Table 3. NDFS (%) 1986 1st and 2nd Harvest and 1987 Harvest

	1986 - 1		1986 - 2		1987	
Treat.	Zero	Conv.	Zero	Conv.	Zero	Conv.
50*- 0	22.3	23.3	13.6	11.2	1.2	0.9
100*- 0	39.4	40.4	21.2	26.3	2.3	2.6
50*- S	23.5	20.9	10.9	10.4	0.9	0.9
100*- S	41.5	37.3	22.1	23.1	1.7	1.7
0 - S*	22.5	26.8*	13.1	13.6	6.1	6.7
50 - S*	16.2	20.8*	9.7	11.1	6.1	5.1
100 - S*	15.4	20.2*	9.3	10.9	6.7	6.6

S = 150 Kg N/ha
1986-1 : first harvest, 1986-2 : second harvest

Table 4. NDFS (%) 1987 1st and 2nd Harvest.

	1987 - 1		1987 - 2	
Treat.	Zero	Conv.	Zero	Conv.
50*- 0	23.6	22.9	12.9	15.2
100*- 0	37.8	36.4	22.6	28.3
50*- S	22.1	23.0	13.7	13.4
100*- S	35.1	39.3	22.8	24.6
0 - S*	3.7*	1.4	1.9	3.4*
50 - S*	3.2*	1.4	2.1	3.9*
100 - S*	3.1*	1.1	1.5	2.9*

S = 60 kg N/ha
1987-1 : first harvest, 1987-2 : second harvest.

Table 5. Utilization of Applied N by Wheat (%) 1986 1st and 2nd and 1987 Harvest

	1986 - 1		1986 - 2		1987	
Treat.	Zero	Conv.	Zero	Conv.	Zero	Conv.
50*- 0	20.4	19.9	24.4	19.4	1.7	1.5
100*- 0	24.0	23.8	23.6	26.7	1.4	1.7
50*- S	23.2	22.4	22.2	22.2	1.6	1.4
100*- S	25.2	21.3	27.7	25.9	1.3	0.8
0 - S*	5.5	6.4	7.0	8.1	3.4	3.1
50 - S*	6.0	7.7	7.9	9.1	3.8	2.6
100 - S*	6.0	8.5	7.9	8.0	3.3	3.2

S = 150 Kg N.ha
1986-1 : first harvest, 1986-2 : second harvest.

Table 6. Utilization of Applied N by Wheat (%) 1987 1st and 2nd Harvest.

	1987 - 1		1987 - 2	
Treat.	Zero	Conv.	Zero	Conv.
50*- 0	24.2	20.8	19.9	20.6
100*- 0	20.9	24.9	23.4	27.6
50*- S	19.8	21.4	19.4	17.4
100*- S	26.6	26.5	19.6	22.3
0 - S*	1.3	0.6	1.7	2.3
50 - S*	2.4*	1.2	2.6	2.7
100 - S*	3.1*	1.3	2.5	4.3

S = 60 kg N/ha
1987-1 : first harvest, 1987-2 : second harvest.

CHROMIUM IN MANITOBA'S AGRICULTURAL SOILS AND ITS POTENTIAL FOR TOXICITY TO PLANTS

M.M. Cheslock and Tee Boon Goh
Department of Soil Science, University of Manitoba

INTRODUCTION

Chromium occurs naturally in the range of 20 to 125 μg/g in Canadian soils (Adriano, 1986), and it is inherited from the parent material in which these soils have formed. These levels are capable of increasing in agricultural soils because many fertilizers and municipal and industrial waste products with fertilizer properties applied to agricultural soils contain chromium.

There are two oxidation states in which chromium exists in soils: these are the trivalent (Cr(III)) state which is quite stable and the hexavalent (Cr(VI)) state which is quite mobile in soils. In soils, chromium is capable of existing in four forms: there are two trivalent forms, the Cr^{+3} cation and CrO_2^- anion and there are two hexavalent anion forms, CrO_4^{-2} and $Cr_2O_7^{-2}$ (Bartlett and Kimble, 1976). Chromium in the trivalent form has been found to be an essential element for human and other mammalian nutrition; the hexavalent Cr, however, is quite toxic in minute quantities. Both forms of Cr are not essential for the normal growth and development of plants, and the hexavalent form is considered as the more toxic form (Skeffington et al., 1976).

The oxidation of Cr(III) to Cr(VI) in soils has caused concern, since there is the potential for toxicity from added trivalent Cr. Although the oxidation of Cr(III) to Cr(VI) has not been reported to occur in the field, Bartlett and James (1979) found the key to the oxidation to be the presence in the soil of oxidized Mn, which serves as an electron acceptor in the reaction.

Despite studies conducted on the behaviour of chromium in soils, and its toxicity to plants, there still exists many questions about where Cr exists in soils and the conditions that exist in soils that can make Cr more available to plants. Therefore, a soil survey of four of Manitoba's agricultural soils was conducted to describe the profile distribution of Cr in terms of the total content of the element and extractable forms. A plant study was also conducted to determine the effects of Cr source and concentration, oxidized manganese, and phosphorous fertilizer on the growth, seed yield and uptake of Cr, Mn, and P.

METHODS AND MATERIALS

Soil Survey

Four soils were sampled according to horizons. The pedons were: soil 1 - Rego Black Gleyed Chernozem, Carbonated Phase; soil 2 - Rego Black Chernozem; soil 3 - Orthic Gray Luvisol; and soil 4 - Rego Humic Gleysol, Carbonated Phase. Each horizon was analyzed for routine soil properties, total Cr and Mn, extractable Cr and the Cr oxidation quick test (Bartlett and James, 1979).

The pH of the horizons was determined in suspensions using water and 0.01 M $CaCl_2$. The texture of the soils was determined by hand texturing in the field. The amount of carbonates (%$CaCO_3$) was measured by an acid-neutralization method (Allison and Moodie, 1965); and the amount of organic matter was measured by using the Walkley-Black method (Allison, 1965).

The total amount of chromium and manganese in each horizon was determined by atomic absorption spectrometry following a concentrated HCl digestion (McBride, 1968).

For extractable Cr the following eight extractants were used: 1. Water - for water soluble Cr, 2. 1M NH_4Cl - for exchangeable Cr, 3. 0.01M KH_2PO_4 - for readily available Cr (hexavalent Cr) (Reisenauer, 1982), 4. 0.1N HCl - for acid extractable Cr (Baker and Amacher, 1982), 5. 2M HNO_3 - for acid soluble Cr (Reisenauer, 1982), 6. 0.1 M $Na_4P_2O_7$ organically bound Cr (Bascomb, 1968), 7. DTPA - for DTPA extractable Cr (Lindsay and Norvell, 1978), and 8. CBD (sodium - citrate - bicarbonate - dithionite method) - for Cr associated with the free oxides (Mehra and Jackson, 1960).

Plant Study

A 5x3x2 factorial experiment, with three replicates, was conducted with the following treatments: 5 levels of Cr - Cr 0 μg/g, Cr(III) 5 μg/g, Cr(III) 50 μg/g, Cr(VI) 5 μg/g and Cr(VI) 50 μg/g; 3 levels of P - 0, 50 and 100 μg/g; and 2 levels of Mn - 0 and 310 μg/g.

Chromium (III) was supplied by $CrCl_3 \cdot 6H_2O$ and chromium (VI) was supplied as K_2CrO_4. The source of manganese was MnO_2 and phosphorous was supplied as monoammonium phosphate fertilizer (11-51-0) in powder form.

The soil selected for this study was the top 0-15 cm of the Rego Black Gleyed Chernozem - Carbonated Phase soil studied in the soil survey.

The growth chamber selected for this study was maintained at a temperature of 24°C, a photoperiod of 16 hours and a light intensity of 600 microeinsteins $\cdot$ m^{-2} $\cdot$ sec^{-1} x 0.1 watt $\cdot$ m^{-2} x 10 lux.

Four kg of the soil was thoroughly mixed with each of the above treatments. As well, a solution containing 100 μg/g of nitrogen supplied from NH_4NO_3 and 40 μg/g of potassium supplied from KCl was added to each treatment. Twelve germinated barley seeds were transplanted in the pots. For the first two weeks of growth, the soil was brought up to 75% of field capacity moisture, using distilled water. After this time, the pots were thinned to 8 plants per pot, and were brought up to field capacity daily. After another week of growth, the pots were thinned to six plants per pot. A second dressing comprising 100 μg/g of nitrogen and 40 μg/g of potassium was applied to each pot after four weeks.

Plant tops were harvested at maturity and air dried. The heads were removed from the straw, counted, and then the grain was separated from the heads. The straw and grain were weighed and then ground in a Wiley mill before digestion in nitric and perchloric acids.

Chromium and manganese in the digests were analyzed by atomic absorption spectroscopy, and phosphorous by the molybdenum - blue method (Murphy and Riley, 1962) by UV - visible spectrometry.

RESULTS AND DISCUSSION

Soil Survey

Table one shows the selected properties of the soils according to horizon. Table two displays the total amount of Cr and Mn found in these soils according to horizon, as well as the amount of Cr(III) that these soils oxidized to Cr(VI), as determined by the Cr Oxidation Quick Test (Bartlett and James, 1979). For total Cr, the profile averages range from 13 (for soil 1) to 27 (for soil 2) μg/g. The profiles contain approximately the same amount of Cr throughout, except in the case of soil 3 where an accumulation of Cr has occurred in the Bt horizon, indicating that the Cr is concentrated in the clay fraction and hence is subject to eluviation with the clay.

The relative ability of a soil to oxidize Cr was determined directly by means of a quick test in which Cr(III) is added to a fresh moist soil sample (Bartlett and James, 1979). The key to this oxidation is oxidized Mn which serves as electron acceptors in the reaction (Bartlett and James, 1979). Table two displays the fact that these soils are capable of oxidizing Cr with the surface horizons having the greatest potential. However, the low values indicate that there does not exist a great potential for toxicity from a Cr(III) source because these soils do not contain sufficient quantities of oxidized Mn in relation to the total amount of Mn. Bartlett and James (1979) also found that the oxidized Mn involved in the oxidation of Cr is made up of a small fraction of the total soil Mn (as shown in Table two), termed "easily reducible".

Table three shows the results of the different extractable forms of Cr. The results show no water soluble Cr and less than 0.10 μg/g of KH_2PO_4 extractable Cr which measures readily available Cr or Cr(VI). DTPA which is used to measure available divalent micronutrients (Lindsay and Norvell, 1978) also extracted some Cr from these soils. Very little Cr was extracted by NH_4Cl, indicating that Cr is not concentrated in the exchangeable form. The acid extraction of Cr, using 0.1 N HCl, was not very effective in obtaining Cr from these soils because these soils are quite calcareous. The 2M nitric acid was, however, quite efficient in solubilizing Cr, probably because it was used in a more concentrated form. Most of the Cr in these horizons is associated with free oxides as seen in the CBD-extraction fraction. There are several reasons why Cr may be concentrated here including the fact that the oxides are highly reactive due to their large surface area and high surface charge. The $Na_4P_2O_7$ fraction is specific for organo - mineral complexes and the results bear correlation with the organic matter content of each horizon. This material probably contains less Cr because of charge neutralization between organic and mineral matter.

Table 1 Characteristics of Soils

Soil	Horizon	pH		% Organic Matter	% Calcium Carbonate	Textural Class
		Water	$CaCl_2$			
1	Ah	8.2	7.8	4.96	12.46	Sandy Loam
	Ac	8.3	7.6	0.49	7.13	Fine Sand
	Ck_1	8.5	7.6	0.16	7.60	Fine Sand
	Ck_2	8.5	7.5	0.21	11.87	Sand
2	Ap	7.0	6.6	6.38	---	Heavy Clay
	Ck_1	8.1	7.3	2.20	12.53	Clay
	Ck_2	7.9	7.8	1.35	12.59	Clay
3	Ae	6.2	5.5	1.12	---	Sand
	Bt	6.6	6.0	1.40	---	Clay
	BC	8.0	7.3	1.13	24.67	S Cl Loam
	Ck	8.1	7.5	0.59	24.66	SI Cl Loam
4	Apk	7.8	7.4	10.19	68.35	Clay
	Ahk_1	8.0	7.6	6.24	57.14	Clay
	Ahk_2	8.1	7.9	2.80	27.74	Clay
	Ckg_1	8.1	8.0	0.98	59.96	Heavy Clay
	Ckg_2	8.2	7.8	1.05	63.04	Heavy Clay

Table 2 Total Chromium and Manganese ($\mu g/g$) and Cr(III) Oxidized ($\mu g/g$)

Soil	Horizon	Total Cr	Total Mn	Cr(III) Oxidized
1	Ah	16.49	405.36	10.12
	Ac	13.44	227.02	3.15
	Ck_1	6.13	139.96	1.32
	Ck_2	14.98	191.46	2.82
2	Ap	29.34	784.01	9.64
	Ck_1	26.47	673.55	0.81
	Ck_2	26.36	657.96	1.42
3	Ae	11.15	812.66	0.87
	Bt	35.67	930.22	1.63
	BC	10.17	533.68	8.71
	Ck	7.28	619.19	5.31
4	Apk	27.11	364.72	5.47
	Ahk_1	26.29	237.99	0.54
	Ahk_2	12.49	202.03	0.41
	Ckg_1	26.03	575.42	0.20
	Ckg_2	26.10	733.76	0.11

Table 3 Extractable Chromium (µg/g)*

Soil	Horizon	DTPA	0.01M NH_4Cl	0.1N HCl	2M HNO_3	CBD	0.1M $Na_4P_2O_7$
1	Ah	1.14	0.27	0.51	4.28	4.23	0.41
	Ac	1.26	0.27	1.01	2.71	3.85	0.22
	Ck_1	1.22	0.17	1.26	2.70	4.16	0.14
	Ck_2	1.38	0.22	1.00	3.57	4.54	0.09
2	Ap	1.56	0.16	0.27	4.63	6.40	2.87
	Ck_1	1.57	0.11	0.27	6.66	6.00	0.83
	Ck_2	1.75	0.16	1.05	6.65	5.56	0.18
3	Ae	0.75	0.00	2.52	1.65	5.89	0.97
	Bt	0.87	0.00	0.00	3.88	10.32	1.62
	BC	0.87	0.00	0.00	6.64	6.30	0.67
	Ck	0.85	0.00	0.00	7.26	5.52	0.35
4	Apk	1.93	0.21	0.83	4.12	4.64	1.59
	Ahk_1	2.14	0.33	1.26	4.14	4.96	2.73
	Ahk_2	2.05	0.16	2.40	2.88	4.41	1.64
	Ckg_1	2.26	0.16	1.63	5.68	5.73	0.76
	Ckg_2	2.18	0.16	0.55	5.95	6.17	1.21

* There was no water soluble Cr.
Values of less than 0.10 ppm were obtained for Cr by the 0.01M KH_2PO_4 extractant.

Plant Study

When the plants were growing visual signs of toxicity were observed only in the treatments which received Cr(VI) 50 μg/g, and as the level of P applied increased, the symptoms of toxicity were reduced. These plants had smaller lighter-coloured leaves compared to the control and no tillers. The 5 μg/g hexavalent Cr treatments produced plants similar to the control; however, they were slower in development compared to the control. For all of the hexavalent Cr treatments there was delayed maturity. All the trivalent Cr treatments (except the Cr(III) 50 μg/g and P 0 μg/g treatments) displayed the same type of growth and development as the control, indicating that the addition of MnO_2 did not cause toxicity from Cr(III) additions. The Cr(III) 50 μg/g and P 0 μg/g treatment produced smaller plants, probably due to a phosphorous deficiency.

Table four displays the grain yield and dry matter produced by the six barley plants per pot. For both of these sets of data, highly significant differences exist among Cr and among P levels. No significant difference occurred among the Mn treatments. A highly significant Cr*P interaction exists (this means that the effects of Cr on the growth and grain yield are dependent on the level of P applied, and vice versa). No other interactions were observed.

For both grain yield and straw production, the control, all Cr(III) treatments (except the 0 μg/g P treatment), and the Cr(VI) 5 μg/g treatment gave similar yields and straw produced. When the Cr(VI) 50 μg/g treatments are considered, significant reductions in seed yield and straw production are noted; for these Cr(VI) 50 μg/g treatments, as the level of P applied increases, there is an increase in grain and straw production, indicating that Cr(VI) toxicity is reduced by P addition. The Cr(III) 50 μg/g and P 0 μg/g treatments gave low yields and straw production probably due to P deficiency.

For grain yield, the treatments containing Cr(III) 50 μg/g and P 100 μg/g gave the highest yield followed by Cr(III) 50 μg/g and P 50 μg/g and the controls followed. This means that Cr(III) 50 μg/g did not affect seed yield as compared to the control, and high levels of P increased yield. This trend was followed as well, by the straw production data.

Manganese dioxide addition did not affect the yield and straw produced, indicating that it did not cause toxicity due to trivalent Cr oxidation. It is probable that Cr(VI) was formed but since no toxicity occurred one can conclude that the amounts of Cr(VI) formed were either insufficient for toxicity or that the Cr(VI) so formed was unavailable to plants due to fixation reactions or to the conversion back to Cr(III). There may also have been nutrient benefit given to the plants by the added Mn.

Table five indicates the amount of Cr, Mn, and P taken up by the above ground parts of the six barley plants per pot. For each element, highly significant differences were found to exist among Cr, and among P levels, and no significant difference occurred for the MnO_2 treatments. Also a highly significant Cr*P interaction exists, indicating that the uptake of each particular element depended upon both the level of Cr and the level of P applied.

Table 4 Grain and Straw Produced by the Six Plants per Per Pot

Treatment			Grain Yield (g/pot)	Dry Matter (g/pot)
	Mn*	P		
Cr 0	0	50	27.03	22.23
Cr 0	1	50	25.25	26.08
Cr(III) 5	0	50	25.11	21.91
Cr(III) 5	1	50	22.97	25.47
Cr(III) 50	0	0	9.31	15.37
Cr(III) 50	1	0	8.00	14.70
Cr(III) 50	0	50	25.95	23.97
Cr(III) 50	1	50	28.30	28.81
Cr(III) 50	0	100	31.63	25.29
Cr(III) 50	1	100	31.72	24.71
Cr(VI) 5	0	50	24.50	21.42
Cr(VI) 5	1	50	28.50	26.91
Cr(VI) 50	0	0	0.47	1.63
Cr(VI) 50	1	0	0.00	0.74
Cr(VI) 50	0	50	5.63	7.16
Cr(VI) 50	1	50	6.84	9.12
Cr(VI) 50	0	100	21.05	16.99
Cr(VI) 50	1	100	14.70	17.03

* For manganese treatments: 0 represents no Mn added, and
1 represents 310 µg/g of Mn added.

The greatest amount of Cr was taken up by the treatments containing Cr(VI) 50 μg/g and P 100 μg/g, Cr(VI) 50 μg/g and P 50 μg/g, and Cr(VI) 5 μg/g and P 50 μg/g. These results, combined with the findings of dry matter and grain production, indicate that as the level of P increases more Cr is taken up from a source of Cr (VI) 50 μg/g and there is a greater yield and dry matter production, despite the increased amount of Cr in the tissues. Also, for a constant level of P at 50 μg/g, more Cr is taken up as the level of Cr(VI) in the soil increases; however, in this case the amount of dry matter and grain produced is reduced due to toxicity. For the Cr(VI) 50 μg/g results indicated above, there exists agreement in the literature with the results of Bartlett and Kimble (1976a) where they found that orthophosphate and hexavalent Cr compete for the same adsorption sites in soils because they both exist as anions, and KH_2PO_4 was the best extracting agent for Cr(VI). This means that as the level of P applied increases there should be less adsorption of Cr(VI) and more Cr available to the plants and therefore, more Cr taken up by the plants. This is exactly what was found in the above results.

For the Cr(III) treatments in Table five there was no significant differences in the uptake of Cr. The control treatments had no Cr taken up either by the straw or the grain.

It should be noted at this time, that the Cr contained as an impurity in the phosphorous fertilizer used in this experiment had no effect on the plant growth because the fertilizer does not contain toxic quantities of Cr and also, the Cr added was probably quickly immobilized by the soil.

For the uptake of Mn, the interesting results are for the Cr(VI) 50 μg/g treatments, which show that as the level of P decreases from 100 to 0 μg/g, the amount of Mn taken up decreases as well. For the Cr(III) treatments there was no significant difference between the treatments; however, one can see that for the Cr(III) 50 μg/g treatments as P increases the level of Mn in the tissues also increases. It is also interesting to note that for the control and all Cr(III) treatments, if Mn was added to the soil there was more taken up by the plants; these differences in Mn uptake, however, are non-significant.

Plant uptake of phosphorous, as shown in Table five, increased as the level of P applied increased. The uptake of P in the control, all the trivalent Cr treatments (except the Cr(III) 50 μg/g and P 0 μg/g treatments) and the 5 μg/g hexavalent Cr treatments resulted in plant P levels which were not significantly different from each other. The least amount of Cr was taken up by Cr(III) and Cr(VI) 50 μg/g treatments which had not been fertilized with P. These low P levels explain why the Cr(III) 50 μg/g and P 0 μg/g treatments resulted in smaller plants compared to the control and it partly explains the poor growth of the plants from the Cr(VI) 50 μg/g and P 0 μg/g treatments. As for the rest of the Cr(VI) 50 μg/g treatments, as the level of P applied increased, more P was taken up. It was most likely that this increased P in the tissues reduced the toxicity of Cr(VI) and increased the straw and grain produced by the plants.

Table 5 Chromium, Manganese and Phosphorous Uptake by the Six Plants Per Pot

Treatment			Total Cr Uptake (µg/g)	Total Mn Uptake (µg/g)	Total P Uptake (µg/g)
	Mn*	P			
Cr 0	0	50	0.00	800.20	90886
Cr 0	1	50	0.00	882.12	96581
Cr(III) 5	0	50	20.57	639.56	94792
Cr(III) 5	1	50	22.49	731.26	75248
Cr(III) 50	0	0	15.14	804.88	22006
Cr(III) 50	1	0	6.52	870.47	22972
Cr(III) 50	0	50	22.16	845.99	73117
Cr(III) 50	1	50	16.97	1073.39	73855
Cr(III) 50	0	100	12.58	962.55	99498
Cr(III) 50	1	100	14.83	1043.54	101998
Cr(VI) 5	0	50	23.49	662.22	74552
Cr(VI) 5	1	50	24.21	839.91	88135
Cr(VI) 50	0	0	14.20	56.03	2530
Cr(VI) 50	1	0	0.37	25.28	1197
Cr(VI) 50	0	50	37.69	241.49	20522
Cr(VI) 50	1	50	36.90	508.99	23356
Cr(VI) 50	0	100	87.09	832.38	52499
Cr(VI) 50	1	100	70.86	760.86	40087

* For manganese treatments: 0 represents no Mn added, and
1 represents 310 µg/g of Mn added.

CONCLUSIONS

For the four representative agricultural soils collected, the results indicate that there is no danger of chromium toxicity, as they presently exist. Furthermore, trivalent Cr additions mainly from fertilizer sources would not present a potential problem for three reasons: (1) The added Cr(III) would be quickly immobilized due to precipitation and adsorption reactions, (2) Although the soils are capable of oxidizing Cr(III), the resultant Cr(VI) levels are quite low, since these soils do not contain sufficient amounts of oxidized manganese compounds to bring about toxic levels of Cr(VI), (3) The resultant Cr(VI) formed may not be available to plants due to fixation reactions and also to the conversion back to Cr(III).

There still exists a potential problem from hexavalent chromium additions, however, since the existence of hexavalent Cr in soils seems to be the key to toxicity.

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ENVIRONMENTAL GUIDELINES FOR LEAD-IN-SOIL CONTAMINATION IN MANITOBA: A CASE STUDY

D. L. Wotton and S. F. Phillips
Terrestrial Standards and Studies
Department of Environment and Workplace Safety and Health
Province of Manitoba

ABSTRACT

The Environmental Management Division of the Province of Manitoba has been studying lead concentrations in urban soils of Manitoba since 1979. Extensive environmental sampling from 1979 to 1981 in the Winnipeg area revealed elevated levels of lead-in-soil adjacent to major traffic arteries and in the vicinity of 3 secondary lead smelters. In 1981 Manitoba Environment adopted a maximum acceptable concentration of lead-in-soil of 2600 µg/g (3000 ± 13%). This guideline was initially accepted as a Canadian standard by the Ontario Ministry of the Environment. The guideline served as an arbitrary criterion for unacceptable lead concentrations in sod and soil of residential areas or areas frequented by children. Soils with unacceptable levels, ie. greater than or equal to 2600 µg/g, were recomended for removal and replacement. During the mid 1980's interest for lead in the environment heightened as federal regulations moved toward banning leaded gasoline. A number of extensive studies were undertaken, most notably by the Royal Society of Canada which in its 1986 report called for a reduction of lead-in-soil guidelines. In 1987 the Ontario Ministry of the Environment lowered its lead-in-soil guideline to 500 µg/g for selected residential areas and 1000 µg/g for industrial sites. In 1988 Manitoba Environment similarly reduced its lead-in-soil guideline in response to a site specific lead contaminationSt problem. A lead level of 500 µg/g for residential and garden soils and 1000 µg/g for industrial areas was used to implement a soil removal and replacement program in a rural community of southern Manitoba.

1.0 INTRODUCTION

Lead is one of the oldest toxins known to mankind. Humans may be directly exposed to lead via inhalation or ingestion of airborne or reentrained particulates or indirectly through absorption or ingestion of contaminated foodstuffs, smoking materials or various other pathways. It is generally accepted that lead burdens in the body are cummulative with time and that children are particularly sensitive (Drill et al 1979, Jaworski 1978). Children between the toddler stage and ages 5 to 7 are in a high risk group. In their play, they often contact soil material, are usually not concerned about handling food with unclean hands and often have the pica habit. Because of their lower body mass, lead concentrations are effectively increased. Furthermore this potential risk of exposure occurs at a stage in life when metabolic systems are rapidly developing and highly sensitive (Bunkreef et al 1981, Coodin et al 1980).

The lead burden from a global perspective has increased dramatically over the past century as a result of industrialization. Our urban centres are particularly susceptible to large accumulations from lead in gasoline. Lead has been used in gasoline since the 1920's and by the early 1970's average Canadian loadings reached the 12,000 ton per year range. Although lead is to be phased out of gasoline by 1990, it will persist in air, water and soil systems. Additional sources of lead in the environment include lead based paints and paint products as well as industrial sources. Industrial sources include atmospheric emissions from smelters or direct deposition to soils from battery-recycling operations and others.

The Province of Manitoba has been monitoring lead in the environment since the early 1970's. Air pollution control programs have implemented emission limits on secondary lead smelters in compliance with provincial air quality standards (Chia-Ei Tsai 1987). Studies of lead-in-soil have been ongoing since 1979 and mitigative actions have been carried out in compliance with guidelines developed for site specific cases (Wotton 1987).

Guidelines for lead-in-soil have been adopted using current Canadian criteria based on best practicable scientific knowledge of the day. Mitigative actions have been based on a preventative action philosophy in keeping with sound environmental management principles. The following information is intended to review and summarize the developmental history of lead-in-soil guidelines in the province of Manitoba.

2.0 INITIAL LEAD-IN-SOIL GUIDELINES 1979-1986

Extensive environmental sampling from 1979 to 1981 in Winnipeg revealed elevated levels of lead-in-soil adjacent to major traffic arteries and in the vicinity of 3 secondary lead smelters in the northwest quadrant of the city (A, B, C in Figure 1). The community of Weston was of particular concern as it had a secondary lead smelter located in the residential area and within 2 city blocks of Weston Elementary School (A in Figure 1). Weston School is also located adjacent to a major traffic artery and is therefore exposed to an unquantified contribution of lead from automobile exhaust.

Environmental guidelines for lead-in-soil were first established in Canada by the Ontario Ministry of the Environment in the mid 1970's (EHB 1976). The acceptable concentration was 3000 ppm (or µg/g) ± 13% which translated to a minimum guideline figure of 2600 µg/g and which Manitoba adopted in 1981 for use in the Weston area of Winnipeg. This guideline was an arbitrary criterion to test for unacceptable lead concentrations in sod and soil of residential areas or areas frequented by children.

Lead concentration was determined in samples of sod and the upper 5 cm (2 in) of soil. Soils with concentrations of 2600 µg/g or higher are recommended for removal and replacement. Sod and soil to a depth of 15 cm was removed and replaced from 26 residential properties and 405 metres of boulevard in the Weston area between 1981 and 1982 (Jones and Wotton 1982). At Weston School concentrations of lead in accumulated dust and soil particulate debris were found as high as 4850 µg/g. In 1981 a commercial vacuum technique was used to remove lead contaminated dust from the paved playground on the north side adjacent to Logan Avenue. One metric tonne of dust and particulate debris was removed. However, concentrations again went up to the 4000 µg/g range prompting a second clean-up in 1983. In the second clean-up operation 1.36 metric tonnes of soil material were removed (Jones 1985). All lead contaminated soils were buried in the City of Winnipeg's Brady Street landfill site. This is the most secure landfill site in the province of Manitoba.

In 1984 remedial action was carried out on the north playground of Weston School by the Winnipeg School Division. The pavement in the playground was removed and replaced with sod, shrubs and trees, and a sprinkler system was installed. Follow-up monitoring of this playground has indicated that the action was successful, and to date, lead levels have not exceeded 500 µg/g.

3.0 REVISED LEAD-IN-SOIL GUIDELINES, 1987

The concern for lead in the environment heightened during the mid 1980's. This was in response to increased information relating lead and health concerns as well as new scientific evidence of lead accumulations occurring in sediments of remote lakes due to long range transport. As the Canadian government moved toward regulations which would remove lead from gasoline a number of extensive studies were undertaken. The most comprehensive review was by the Royal Society of Canada's Commission on Lead in the Environment. Their report, "Lead in the Canadian Environment: Science and Regulation", was released in September 1986. This report recommended a reduction of lead-in-soil guidelines to 500 µg/g for industrial, commercial sites and parklands (Hare 1986).

Concurrent with the release of the Royal Society's report, the Ontario Ministry of the Environment was embarking on a large scale lead clean-up program in the South Riverdale area of Toronto. A Lead-in-Soil Committee was appointed by the Minister of the Environment to provide recommendations for a scientifically defensible guideline for removal of lead contaminated soil. This committee was composed of technical and medical experts from the scientific community, representatives of 3 levels of government, community health groups, neighbourhood representatives and the secondary lead smelter industry.

In May 1987 the Lead-in-Soil Committee released its report entitled "Review and Recommendations on a Lead-in-Soil Guideline" which recommended soil guidelines in 3 specific areas:

- 500 µg/g for agricultural areas where root and leafy vegetables are grown
- 500 to 1000 µg/g for areas to which children have routine access
- 1000 µg/g for areas to which children do not have routine access

The Committee recognized that in evaluating guidelines for areas of routine access by children an assessment of socio-economic and technical factors must be done on each site specific case. The Ontario Minister of the Environment then selected the guideline level of 500 µg/g for soil removal in South Riverdale where children were known to have elevated lead-in-blood levels and where a secondary lead industry was located. By accepting this lower lead guideline the Ontario government entered into a multi-million dollar program which was estimated to affect some 1000 residents.

4.0 ADOPTION AND IMPLEMENTATION IN MANITOBA, 1988

In 1988 Manitoba Environment adopted and implemented Ontario's new guidelines as clean-up criteria for soil contaminated by lead from a central area of Roland, a small rural community southwest of Winnipeg. A local scrap yard located adjacent to residential property had been crushing batteries and removing lead plates in an environmentally unacceptable recycling operation. As a result soil had been significantly contaminated to a depth of 50 cm. The site was not fenced and therefore was accessible to children that might play there. In addition, there was considerable potential for off-site migration by wind or water run-off.

In March 1988 surface soil samples were collected along transects radiating away from the scrap yard and results indicated that contamination was restricted to the scrap yard and surrounding ditches. Follow-up sampling was carried out at 8 locations in the scrap yard proper and at 3 locations in the adjacent ditch. Soil samples were obtained from the following depths: 0, 10 cm, 20 cm, 30 cm, 50 cm, 1 metre and 2 metres. Lead concentrations exceeded guidelines by several orders of magnitude in soils down to a depth of 30 cm (Table 1). Garden soils in the adjacent residential properties were also tested to depths of 50 cm but were below the 500 µg/g guideline.

In November 1988 a remedial program to remove and replace contaminated soils was implemented. Leachate tests were conducted on the contaminated soil to determine if it met the hazardous waste criterion. The soil did and was therefore designated for disposal by landfill. The soils containing the highest levels of lead were removed first and shipped to the Brady Street landfill site in Winnipeg. Soils of lesser concentration were subsequently buried in the local municipal landfill in an appropriate manner. All replacement soils were analyzed to ensure compliance with minimum lead content, and had less than 250 µg/g.

In summary the Province of Manitoba has recognized the need to maintain lead levels in soils below levels of 500 µg/g for residential and garden properties, and 1000 µg/g for industrial, commercial or parkland sites. This guideline has been adopted as a level where remedial actions may be required. The guideline is intended as a preventative measure and is subject to evaluation of potential sites at risk on an individual basis.

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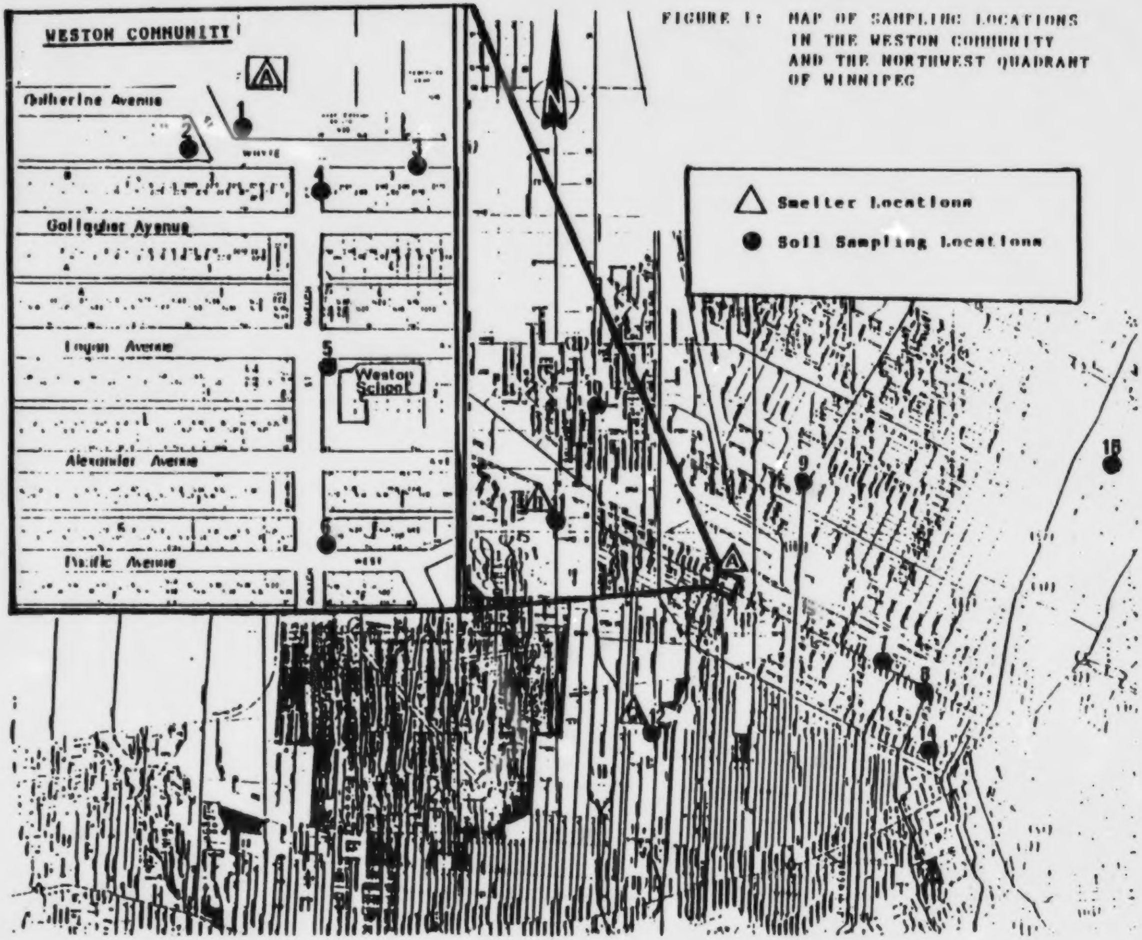
TABLE 1: SUMMARY OF LEAD-IN-SOIL FROM SURFACE TO 2 METRE DEPTH - ROLAND, MANITOBA, 1988

SAMPLE	LOCATION	LEAD CONCENTRATION IN PPM BY SOIL DEPTH						
		0-5 cm	10 cm	20 cm	30 cm	50 cm	1 metre	2 metres
A 1	SW corner scrap yard	4,530	2,240	1,590	425	711	117	117
A 2	W main crushing area	233,000	317,000	308,000	1,960	224	33	2,930
A 3	NE loading area	31,700	933	47	19	28	33	33
A 4	N side drive through	38,200	7,930	6,530	355	98	37	345
A 5	E side drive through	10,300	5,160	16,900	1,310	336	5	19
A 6	E side scrap area	1,590	2,310	355	233	37	5	70
A 7	S side drive through	126,000	19,600	10,300	1,910	28	9	47
A 8	E main crushing area	285,000	7,460	420	121	28	33	47
D 1	Ditch N of lane	20,400	13,100	14,500	33	33	37	47
D 2	Ditch N of crush site	22,400	14,900	159	84	37	14	37
D 3	Ditch S of lane	532	177	70	84	23	47	75

FIGURE 1: MAP OF SAMPLING LOCATIONS IN THE WESTON COMMUNITY AND THE NORTHWEST QUADRANT OF WINNIPEG


WESTON COMMUNITY
Catherine Avenue
Gallagher Avenue
Logan Avenue
Alexander Avenue
Pacific Avenue
Weston School
N
Smelter Locations
Soil Sampling Locations
1
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6
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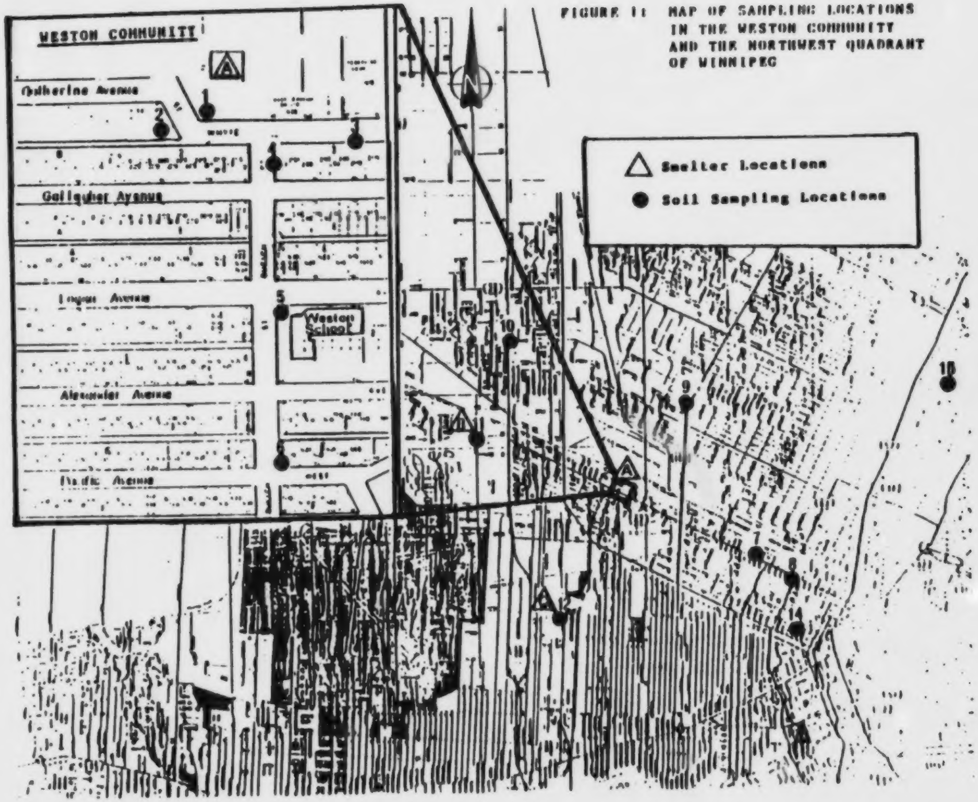
12
15


WESTON COMMUNITY
Catherine Avenue
Gallagher Avenue
Logan Avenue
Weston School
Alexander Avenue
Pacific Avenue
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△ Smelter Locations
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FIGURE 11: MAP OF SAMPLING LOCATIONS IN THE WESTON COMMUNITY AND THE NORTHWEST QUADRANT OF WINNIPEG

Residual Effects of $CuSO_4$ on Yield of Barley and an Assessment of Plant and Soil Analysis as a Means of Predicting Cu Fertilizer Requirements on Organic Soils

R. E. Dowbenko, G. J. Racz and Tee Boon Goh,
Department of Soil Science, University of Manitoba

Introduction

Approximately 120,000 ha of organic soil are currently under cultivation in Manitoba. Potentially, there are 600,000 ha of organic soils which may be suitable for agricultural production. Previous fertility studies conducted in Manitoba have indicated that copper deficiency is a major limitation to small grain production on organic soils (Reid 1982, Tokarchuk 1982). Copper, as $CuSO_4 \cdot 5H_2O$, is usually applied to alleviate this deficiency. Even though yields are greatly increased when copper sulfate is applied, the cost of fertilization may in instances exceed the value of the yield increase in the year of $CuSO_4$ application. Applications of $CuSO_4$, however, continue to have an effect on crop growth beyond the season in which it is applied; the effect of any one application usually decreases with time. Residual effects of Cu fertilization on plant tissue Cu content and grain yield have been shown to occur for 5 or more years after the initial application (Pizer et al. 1966; Reith 1968; Reuter 1975). Information regarding the residual effectiveness of $CuSO_4$ in Manitoba was very limited and thus the economic benefits including the residual effects of $CuSO_4$ could not be accurately ascertained. Also, application of copper fertilizer in excess, due to annual applications over a period of time, can have a deleterious effect on plant growth. Thus a means of predicting the requirement for copper on previously fertilized and unfertilized soil was needed to ensure sound copper fertilizer practices for organic soils.

Materials and Methods

Field trials were established in 1985 and 1986 on organic soils in the northern, south eastern, and east central regions of Manitoba. Some of the chemical and physical properties of the field sites are shown in table 1.

The field plots consisted of two types. Experiments initiated in 1985 consisted of two Cu treatments (0, 10 Kg Cu ha^{-1}). Experiments initiated in 1986 were composed of three Cu treatments (0, 5, and 10 Kg Cu ha^{-1}) The residual effects of Cu applied in 1985 and 1986 were assessed in 1987 and 1988 using barley as a test crop. At each site, the original treatments were split, with 0 and 5 Kg ha^{-1} Cu as $CuSO_4$ being applied. The $CuSO_4 \cdot 5H_2O$ applied (25% Cu) was fine granular fertilizer grade. Broadcast applications were attained using a Valmar fertilizer spreader, all plots were then rotovated to a depth of approximately 15 cm and evenly packed using a cylindrical cast iron rolling drum.

Table 1 Physical and Chemical Characteristics of Soils Used in the Field Studies

Site No	1	2	3	4	5	6	7
Legal Location	SW ¼ 33-9-12E	NE ¼ 14-12-11E	NW ¼ 26-12-11E	NW ¼ 14-15-10E	SE ¼ 12-2-9E	NE ¼ 21-1-11E	NE ¼ 36-25-3E
Organic Matter (%)	73.4	69.5	59.5	68.2	70.0	64.3	67.0
pH	6.9	7.5	5.6	6.4	7.6	7.2	6.5
Salinity (ms cm^{-1})	1.3	0.7	0.4	0.7	0.6	0.7	1.2
NO_3-N (Kg ha^{-1})*	36	64	136	96	61	104	124
$NaHCO_3$ extr. P (Kg ha^{-1})	6.1	15.2	7.0	8.6	3.2	7.8	8.3
NH_4Ac extr. K (Kg ha^{-1})	29	151	81	136	68	64	99
SO_4-S (Kg ha^{-1})	12+	12+	12+	12+	12+	12+	12+
Ca (exch. mg g^{-1})	46.6	37.6	40.2	30.4	37.2	44.6	32.8
Mg (exch. mg g^{-1})	3.2	3.2	2.9	2.2	2.0	3.7	4.1

* Amount of NO_3-N in the 0 to 60 cm depth of soil. Other physical and chemical characteristics are for the 0 to 15 cm depth.

Basal treatments of N, P, and K were applied to each experimental field site in both years according to soil test recommendations to ensure that available macronutrients did not limit yields. Barley (Hordeum vulgare var Argyle) was seeded as a test crop at a rate of 93 Kg ha^{-1}. As required, each experimental site was treated with Roundup ten to fourteen days prior to seeding.

Early season weed control was accomplished through a tank mix of MCPA and Banvel at recommended rates.

Soil Sampling and Soil Analysis

Soil samples were obtained in the spring from the 0-15 cm depth prior to fertilization on all experimental sites and treatments. Samples from nine to eighteen sites on each treatment were taken and composited. Each sample was air-dried, crushed with a wooden roller, and passed through a 2 mm plastic mesh sieve. DTPA-extractable Cu on the soil samples was determined using the DTPA-$CaCl_2$ method (0.005 M DTPA, 0.1 M triethanolamine, and 0.01 M $CaCl_2$ adjusted to pH 7.3) of Lindsay and Norvell (1978). Two grams of soil was extracted with 20 ml of extracting solution using a 1 hr shaking period. The suspensions were then centrifuged at 12,000 rpm for 15 min. The copper concentration in the supernatant was determined by atomic absorption spectrophotometry.

Plant Sampling and Analysis

Plant samples were obtained twice during the crop season. Entire barley plants were sampled at time of heading and at maturity. Four 1-m^2 samples were taken from each treatment plot. At maturity plant samples were air-dried, threshed and weight of grain determined.

Plant material was ground in a Wiley mill and a 1-g sample digested using 5.0 ml concentrated HNO_3 and 2.5 ml 70% $HClO_4$. The copper content of the digest was determined using a Perkin-Elmer 303 atomic absorption spectrophotometer.

Statistical Analysis of Data

In 1985 and 1986 the experimental sites were designed as demonstration field strips, and altered to completely randomized split plot designs in 1987. Yield data was analyzed using Duncan's multiple range test.

Percent yields for all field sites were plotted against plant tissue Cu concentration and DTPA-extractable Cu according to a derivation of the Langmuir adsorption isotherm . The form of which is; $y = x/(a + bx + cx^2)$, where y = % yield, x = level of tissue or soil Cu, and a, b, and c are constants calculated from a quadratic regression analysis of x vs. x/y.

Results and Discussion

Yields of barley were increased by $CuSO_4$ applications for periods of at least 3 to 4 years after application (table 2,3). Although the application of $CuSO_4$ was shown to have extremely good residual effects, all sites responded to reapplication of Cu. Average yields without Cu fertilizer were 1668 Kg ha^{-1} in 1987 and 1534 Kg ha^{-1} in 1988, respectively. Yields in 1987 and 1988 were 2477 Kg ha^{-1} and 3644 Kg ha^{-1}, respectively, on plots previously treated with 10 Kg Cu ha^{-1}. Adding Cu at 5 Kg ha^{-1} in 1987 to plots previously treated with 10 Kg Cu ha^{-1} in 1985 or 1986 (sites 1, 2,3,5, and 7) increased yields from 2369 Kg ha^{-1} to 2547 Kg ha^{-1} in 1987 and from 3324 Kg ha^{-1} to 3813 Kg ha^{-1} in 1988. Applications of 10 or 5 Kg Cu ha^{-1} as copper sulfate were shown to have good residual effect, however, reapplication of Cu in addition to that originally added, was required to maximize yield.

The Cu content of the plant at the heading stage was assessed as a means of predicting plant available soil Cu on organic soils. Plant Cu content was not closely related to yield (fig.1). However, plant Cu was reasonably closely related to response to copper fertilization (fig.3). This indicates that tissue analysis at heading would be useful in predicting the need for Cu application.

Soil Cu level, as assessed by DTPA-extraction , was closely related to both yield (fig.2) and response to Cu fertilization (fig.4). Grain yield was usually low when DTPA-extractable Cu levels in the soil were below 2 $\mu g\ g^{-1}$ (fig.2). Yields were usually high when DTPA-extractable Cu levels in the soil exceeded a value of about 16 $\mu g\ g^{-1}$. Large increases in yield were usually obtained when the soil contained less than 7 μg Cu g^{-1} soil. Yield increases due to Cu fertilization were small when the soil contained high levels of DTPA-extractable Cu, i.e. greater than 16 μg Cu g^{-1} soil.

Table 2 Effect of Previously and Newly Added $CuSO_4$ on Yield of Barley (1987)

Initial Application Rate* (Kg Cu ha^{-1})	0		5		10	
New Application Rate	0	5	0	5	0	5
Site No						
1	--	2715	--‡	--	3123	3545
2	1798	3590	2298	2953	2580	2723
3	460	1985	--	--	1800	1625
4	3920	3655§	3800	3808	3833	4233
5	898	1401	--	--	370	713
6	1510	--	--	--	1660	--
7	3090	3725	3750	3950	3973	4128

* Date of Initial Application Sites 1, 3 and 5: Spring 1985
Sites 2, 4 and 7: Spring 1986
Site 6: Spring 1984.

‡ Treatment not included in experiment.

§ Application rate in 1987 at 20 Kg Cu ha^{-1}.

Table 3 Effect of Previously and Newly Added $CuSO_4$ on Yield of Barley (1988)

Initial Application Rate[*] (Kg Cu ha^{-1})	0		5		10	
1987 Application Rate	0	5	0	5	0	5
Site No						
1	730	4140	--[‡]	--	4295	4425
2	990	2858	3095	4360	3338	4525
3	148	3680	--	--	4480	4513
4	2930	4023[§]	3085	4005	4170	4205
5	353	490	--	--	300	635
6	3620	--	--	--	4716	--
7	1965	3795	3265	3885	4208	4965

[*] Date of Initial Application
Sites 1, 3 and 5: Spring 1985
Sites 2, 4 and 7: Spring 1986
Site 6: Spring 1984.

[‡] Treatment not included in experiment.

[§] Application rate in 1987 at 20 Kg Cu ha^{-1}.

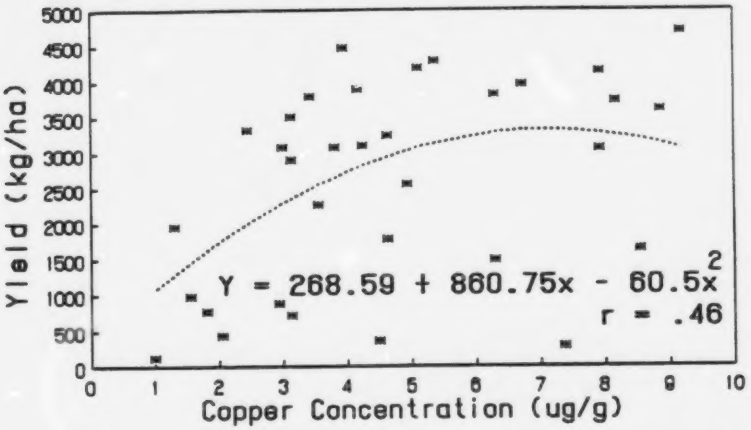

FIGURE 1. Grain Yield vs. Tissue Copper Level Heading Stage (Residual Treatments)

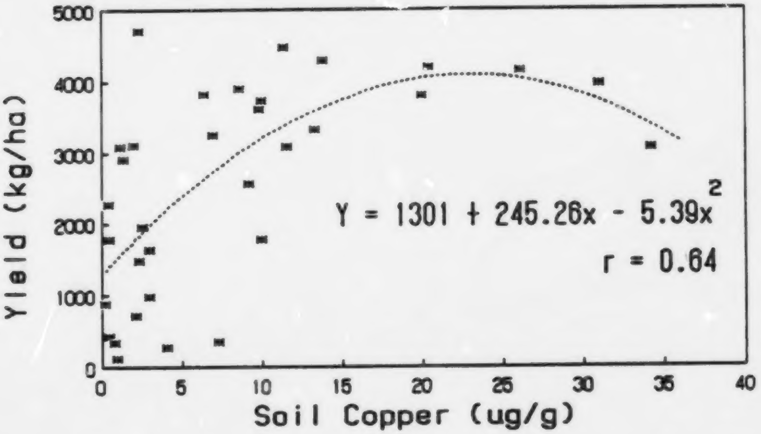

FIGURE 2. Grain Yield vs. Spring DTPA extr. Cu (Residual Treatments)

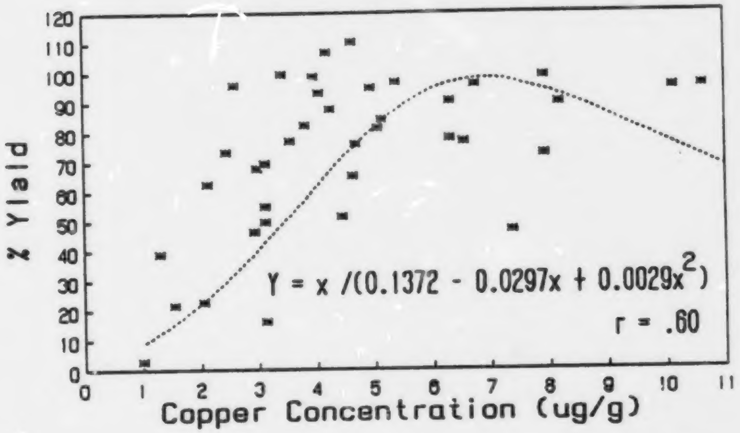

FIGURE 3. % Yield of Barley vs. Tissue Copper Level

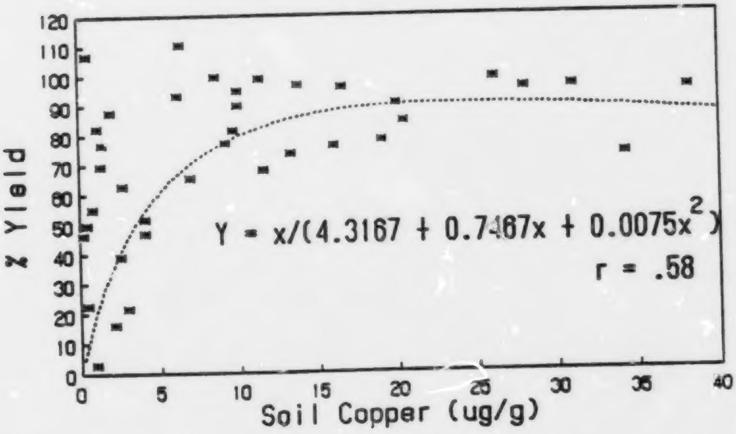

FIGURE 4. % Yield of Barley vs. Spring DTPA extr. Cu

Conclusion

Copper fertilization increased yields of barley grown on Cu deficient organic soils in Manitoba. Cu applied as $CuSO_4 \cdot 5H_2O$ at rates of 5 and 10 Kg ha^{-1} increased yields of barley for 3 to 4 years after application, which was the duration of the study.

The requirement for Cu fertilization may be determined by both the DTPA-extractable Cu soil test and tissue analysis at heading. The utility of the two methods of analyses would suggest that the DTPA-extractable Cu test shows more promise than the Cu content of plant tissue in predicting the initial need for Cu fertilization, or the need for Cu reapplication.

The critical plant tissue Cu level was found to be 5.6 $\mu g\ g^{-1}$ for barley grown on organic soils in Manitoba. Organic soils containing less than 7 $\mu g\ g^{-1}$ Cu were found to be insufficient in plant available Cu, whereas soils containing 8 to 16 $\mu g\ g^{-1}$ Cu and greater than 16 $\mu g\ g^{-1}$ Cu were found to be marginal to sufficient, respectively.

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Root Growth and Zn Uptake by Wheat as Affected by $ZnCl_2$ and ZnEDTA Fertilizer Bands

A. S. Nyaki and G. J. Racz
Department of Soil Science, University of Manitoba

Introduction

The effectiveness of various Zn fertilizers as well as various methods of application of Zn fertilizers in supplying Zn to various crops has been widely studied. (Brown and Krantz 1966, Boawn 1973 and Loewen-Rudgers et al 1978). Studies conducted on soils with a wide variation in physical and chemical characteristics clearly demonstrated that banding of inorganic Zn fertilizers such as $ZnCl_2$ or $ZnSO_4 \cdot 7H_2O$ resulted in very poor or no utilization of fertilizer Zn by most crops. In contrast, Zn uptake by plants was significantly increased when inorganic Zn fertilizers were thoroughly mixed with the soil. (Hedayat et al 1977). Many researchers attribute the low uptake of Zn by plants from inorganic Zn fertilizer bands to poor accessibility of the plants roots to the fertilizer. Therefore, it is currently recommended that in order to improve the contact between plant roots and the Zn fertilizer, inorganic sources of Zn should be mixed thoroughly with the soil before seeding.

It has been shown that chelated forms of Zn such as ZnEDTA are more effective than inorganic Zn fertilizers in supplying Zn to the plant when both are applied as fertilizer bands, at least in part due to the greater solubility and movement of Zn from the ZnEDTA fertilizer bands. Nyaki and Racz (1988), for example, showed that the solubility as well as movement of Zn from $ZnCl_2$ fertilizer bands was very limited, when compared to the solubility and movement of Zn from ZnEDTA fertilizer bands, particularly when the $ZnCl_2$ was applied to a calcareous soil of high pH or when certain forms of N or P were included in the fertilizer band. The greater solubility and movement of Zn from the ZnEDTA fertilizer bands results in a larger volume of soil fertilized with Zn and thus a larger volume of fertilized soil in contact with plants roots.

Studies with other nutrients have also revealed that in addition to the importance attached to the size of fertilizer reaction zones in influencing nutrient uptakes from fertilizer bands, root growth habits within the fertilizer band also affect the extent of nutrient uptake from the fertilizer bands. Strong and Soper (1973), for example, showed that the characteristic feeding habits for P from P fertilizer bands could largely be explained by the inherent properties of the root system in the fertilizer band. Root systems of crops which recovered large amounts of P from the fertilizer bands were found to proliferate extensively within the reaction zone of applied P. The observed root growth habits in P fertilizer bands may at least partly explain why banding of P at seeding time has proved to be very effective in supplying P to most crops.

There were no reports in the literature regarding studies on root growth habits in Zn fertilizer bands. Therefore, a series of Growth Chamber studies were initiated to determine the influence of $ZnCl_2$ and ZnEDTA fertilizer bands on root growth and Zn uptake by wheat grown on Willowcrest Fine Sand and Almasippi Loamy Fine Sand soils.

Materials and Methods

The effect of $ZnCl_2$ and ZnEDTA fertilizer bands on root growth and Zn uptake by wheat was studied using two Willowcrest Fine Sand soils and an Almasippi Loamy Fine Sand soil. All three soils were low in DTPA extractable Zn. (Table 1). Three different experiments were conducted. The first experiment was conducted on the Almasippi Loamy Fine Sand soil to determine the effect of Zn fertilizer treatment, rate of Zn applied and the size of Zn fertilizer band on root growth and Zn uptake from the fertilizer bands. The soil was air dried and then sieved through a 2 mm sieve. 5000 g of the sieved air dry soil was then weighed into plastic pots. Before application of the Zn treatments the soil in each pot was thoroughly mixed with NPK and Cu fertilizers as basal treatments. The respective rates of application were 100 ppm N as $(NH_4)_2SO_4$, 50 ppm P as KH_2PO_4, 200 ppm K as KH_2PO_4 and KCl and 5 ppm Cu as $CuSO_4 \cdot 5H_2O$, all rates based on 5000 g of soil. The various nutrient carriers were dissolved in distilled deionized water and the respective nutrients added to the soil in 25 mls of the nutrient solution.

The Zn treatments consisted of two Zn fertilizers, $ZnCl_2$ and ZnEDTA applied at five different rates 0, 0.63, 1.26, 2.52, and 5.03 mg Zn cm^{-2}. The various rates of Zn were applied in solution form to the surface of soil contained in acrylic cylinders of two different sizes. Both cylinders were 5 cm long and open at both ends but the areas at the open ends were 15.89 cm^2 and 32.15 cm^2. The two different areas were used to represent the two sizes of the Zn fertilizer band referred to in this experiment. The cylinders were first closed on one end with parafilm and then the 15.89 and 32.15 cm^2 cylinders filled with 100 g or 200 g of soil, respectively, which had been treated with NPK and Cu as described before. The various Zn rates were then added in solution form to the surface of the soil in the cylinders. For a particular rate of Zn the concentration of Zn in both sizes of fertilizer bands was maintained constant by adding amounts of Zn in proportion to the size of the fertilizer band. In this experiment the smaller band sizes were treated with 25 mls of the Zn solution while the larger bands were treated with 50 mls of the Zn solution. The solutions were spread as uniformly as possible over the entire band area. After application of the various Zn treatments the parafilm covering one end of the cylinders was carefully removed and the cylinders placed approximately in the middle of the pots such that the top surface of the cylinders was approximately 5 cm below the surface of the soil in the pot. This was achieved by removing 3500 g of soil from the pot, placing the cylinder containing the Zn treatments on the surface of the soil remaining in the pot and then replacing the soil that was removed from the pot.

Ten wheat seeds (variety Columbus) were placed approximately 2.5 cm deep and about 2.5 cm above the Zn fertilizer bands. Ten days after emergence the plants were thinned to 5 plants per pot. The plants were grown in the growth chamber to the flowering stage which occurred about sixty-five days after seeding. Plants were watered to field capacity moisture content everyday using distilled deionized water. During the growing period the plants received an additional 150 ppm N as $(NH_4)_2SO_4$ applied in split application; 100 ppm N was applied 28 days after emergence and the remaining 50 ppm N was applied 50 days after emergence. The appropriate amount of nitrogen was added to the surface of the soil by adding it to the water during the watering process. The plants were grown under 16 hours of artificial light and 8 hours of darkness. Temperatures were maintained at 22°C and 16°C during the day and night periods, respectively. The relative humidity in the growth chamber was kept at 40% during the day and 70% at night. The light intensity close to the plants canopy ranged from 500 to 550 $\mu E\ m^{-2}\ S^{-2}$.

At the flowering stage the plant tops were harvested by cutting the plant shoots at the soil surface using a sharp knife. The plant shoots were then dried in paper bags to constant weight at 65°C, and this was reported as the shoot dry matter yield. The cylinders in the pots were carefully removed from the rest of the soil in the pot by slicing off the soil and roots around them using a sharp knife. The contents of the cylinders were transferred to a 50 mesh sieve and the roots carefully separated from the soil by washing the soil through the sieve. When the roots were soil free they were transferred to paper envelopes and dried at 65°C to constant weight, which was reported as root dry matter yield in the fertilizer bands.

The plant shoots were ground in a Wiley Mill and one gram of the ground sample was predigested in 5 mls HNO_3 and 2.5 mls 70% $HClO_4$ for about half an hour. The samples were further digested on a digestion block at 230°C until the contents in the digestion tubes turned clear. The samples were then cooled and contents washed into 25 ml volumetric flasks and made up to volume. Zn concentration in the digest were then determined using an Atomic

Absorption Spectrophotometer.

The second experiment was conducted on the slightly calcareous Willowcrest Fine Sand soil to determine the effect of a wider range of Zn rates as well as soil type on root growth and Zn uptake from the $ZnCl_2$ and ZnEDTA fertilizer bands. The experiment was conducted on Growth Benches and all the Zn treatments were applied to only one size of fertilizer band which was 15.89 cm^2. The rates of Zn used in this experiment were 0, 0.16, 0.63, 2.52, 5.03, and 10.06 mg Zn cm^{-2}. The fertilizer band was formed using acrylic tubing cylinders using the same procedures as described for the first experiment. The soil was also prepared as described before. Applications of the basal treatments, seeding, maintenance of plants, harvesting and digestion procedures were similar to those described for the first experiment except that since the plants were grown on the growth benches the temperature, relative humidity and the light conditions were not as effectively controlled as in the first experiment.

The third experiment was conducted on the noncalcareous Willowcrest Fine Sand to evaluate the effect of limited incorporation of the Zn fertilizers into the soil on root growth and Zn uptake from the fertilizer bands. Incorporation of the Zn fertilizers into a limited amount of soil was done in an attempt further vary the concentrations of Zn in the fertilizer band, since results from the second experiment showed that when Zn was applied to the surface of the cylinders rates of Zn as low as 0.16 mg Zn cm^{-2} still reduced root growth in the fertilizer band significantly.

The experiment was conducted in the growth chamber in a completely randomized design with treatments arranged in a factorial design. The procedures used in the preparation of the soil, application of the basal treatments, maintenance of the plants, harvesting and digestion of the plant samples were similar to the one described for the first experiment. All the Zn fertilizer treatments were also applied to acrylic cylinders, but instead of applying the Zn solution to the surface of the soil in the cylinders the solution was mixed throughout the 200 g of soil contained in the cylinders. In this experiment the large cylinder size of area 32.15 cm^2 at the open end was used, and the rates of Zn applied were 0.02, 0.05, 0.10, 0.20, 0.40, 0.80, 1.60, and 3.20 mg Zn cm^{-3}.

Incubation Studies

In conjunction with the plant growth studies soil samples with treatments similar to those used in the plant growth studies were incubated at field capacity moisture content for a period of 14 days and then the amount as well as the forms of Zn (Complexed vs Ionic) in soil solution determined. For the soils used in the first two experiments, 360 g of respective soil was placed in columns formed by fitting together two acrylic rings, each 2.5 cm high and 9.5 cm internal diameter, using a standard electrician tape. One end of the column was closed using a parafilm. The columns formed were therefore, 5 cm high, and had an area of 76.02 cm^2 at the open end. $ZnCl_2$ and ZnEDTA each at rates of 0, 0.63, 1.26, 2.51, and 5.03 mg Zn cm^{-2} contained in 40 mls of Zn solution were uniformly spread to the surface of the soil used in the first plant growth study and rates of Zn equivalent to 0, 0.16, 0.63, 2.52, 5.03, and 10.06 mg Zn cm^{-2} were applied to the soil used in the second plant growth study. Before the addition of the Zn treatments 39.2 and 38.8 mls of distilled deionized water were added to the respective soils in the columns so that when the Zn solution was added the soil was approximately at field capacity. The tops of the columns were covered with perforated parafilm to prevent rapid evaporation at the soil surface as well as ensure adequate aeration at the soil surface. After 14 days of incubation at room temperature about 1.5 cm depth of the soil was sliced off and transfered to 250 mls centrifuge bottles. The moisture content of the samples was further raised to about 27.0% and then the supernatant obtained by centrifuging the samples at 10,000 rpm for 40 minutes. The total as well as the ionic form of Zn in the supernatant was determined as follows:

1) The supernatant was first filtered through a Whatman no. 42 filter paper.

2) A portion of the filtered sample was diluted accordingly and the concentration of Zn in soil solution determined using Atomic Absorption Spectrophotometer. This was considered to be the total amount of Zn in soil solution.

3) Another portion of the supernatant was placed in 15 mls centrifuge bottles and 1 drop of 5 M NaOH added to each sample. The mixture was allowed to stand for a period of 2-3 hours.

4) The precipitate formed was then filtered out using Whatman no. 42 filter paper.

5) The clear solution obtained was diluted accordingly and the concentration of Zn in soil solution determined as described before. This was considered to be the amount of the complexed forms of Zn in soil solution.

6) The complexed form of Zn was then subtracted from the figure obtained for total Zn and the difference was the amount of ionic Zn in soil solution.

The same procedure was used to obtain the total as well as the amount of ionic Zn in soil solution for the soil used in the third plant growth study. However, for this soil the various rates of Zn (0, 0.02, 0.05, 0.10, 0.20, 0.40, 0.80, 1.60 and 3.20 mg Zn cm^{-3}) were also applied in 40 mls of Zn solution, but instead of applying the Zn solution to the surface of the soil it was mixed throughout 200 g of soil contained in 250 mls centrifuge bottles. An additional 18.8 mls of distilled deionized water was added to bring the soil close to field capacity moisture content. The moisture content was further raised to 35% just before the samples were centrifuged.

Results and Discussion

Table 1. Some Physical and Chemical Characteristics of the Soils Used

Soil Characteristics	Willowcrest FS	Willowcrest FS	Almasippi LFS
pH (1:1 Soil : Water)	7.00	7.90	8.40
Inorganic Carbon (% $CaCO_3$)	0.20	1.01	4.10
Organic Matter (%)	2.47	2.38	2.70
DTPA Extr. Zn (µg g-1)	0.50	0.60	0.50
Field Capacity (%)	29.4	21.9	22.00

Shoot and Root Dry Matter Yield

Shoot and root dry matter yield (weight of roots recovered from the $ZnCl_2$ and ZnEDTA fertilizer bands) for wheat grown on the calcareous, slightly calcareous and the noncalcareous soils are shown in tables 2, 3 and 4 respectively. Shoot yield for wheat grown on all three soils was not significantly affected by any of the treatments applied. In contrast, the amount of roots in the fertilizer bands was affected by treatments in many instances. Application of $ZnCl_2$ to the calcareous soil did not affect the amount of roots in the fertilizer band, regardless of the rate of Zn applied or the size of the Zn fertilizer band. (Table 2). However, when ZnEDTA at a rate of 5.03 mg Zn cm^{-2} was applied to the same soil, root growth in the larger fertilizer band was significantly decreased. Both Zn fertilizers reduced root growth in the fertilizer bands when applied to the slightly calcareous soil even at rates of Zn as low as 0.16 mg cm^{-2}. (Table 3). Root growth in the fertilizer band tended to decrease with amount of Zn added, particularly for the $ZnCl_2$ treatments. The large reductions in root growth in the $ZnCl_2$ fertilizer band was not evident in the previous experiment when similar amounts of Zn were applied to a band of the same size. (Table 2). Thus, the data shows that root growth in Zn fertilizer bands can vary considerably with soil type.

The effect of incorporating the Zn fertilizers into a limited volume of soil on root dry matter yield in the fertilizer reaction zone is presented in table 4. The amount of roots recovered from the two Zn fertilizer bands was significantly affected by both the source as well as the rate of Zn applied. The two Zn fertilizers varied considerably in the extent to which they affected root development in the Zn fertilizer reaction zone. ZnEDTA was more detrimental to root growth in the fertilizer band than $ZnCl_2$ applied at similar rates for virtually all the rates of applied Zn. (Fig 1). Application of ZnEDTA at rates as low as 0.02 mg Zn cm^{-3}, resulted in a considerable reduction in root growth in the fertilizer band when compared to the control treatment. The amount of roots in the ZnEDTA fertilizer band initially decreased very rapidly with amount of Zn added and then remained relatively constant when more than 0.8 mg Zn cm^{-3} were applied (Fig. 1). Application of ZnEDTA at rates greater than 0.8 mg Zn cm^{-3} resulted in about a 75 percent reduction in root dry matter yield in the fertilizer band. In contrast to the data obtained with ZnEDTA, plants treated with 0.2 to 0.8 mg Zn cm^{-3} as $ZnCl_2$ showed a slight root proliferation in the fertilizer band when compared to the control treatment. Maximum root growth in the $ZnCl_2$ fertilizer band occured at about the 0.63 mg Zn cm^{-3} rate. A sharp decrease in root growth in the $ZnCl_2$ fertilizer band occurred when more than 0.8 mg Zn cm^{-3} was applied.

A visual inspection of roots from all treatments was conducted using a microscope. Root branching was severely reduced by all rates of ZnEDTA with decrease in branching being more evident at the high rates of Zn. Plants treated with $ZnCl_2$ showed a reduced root branching only at the high rates of applied Zn. In addition to reduced root branching, roots recovered from treatments receiving high rates of Zn as $ZnCl_2$ or ZnEDTA also showed a considerable increase in thickness suggesting that at high rates of Zn the surface area per unit weight of roots in the fertilizer band may be reduced substantially.

Zinc Concentrations in Plant Shoots

Zinc concentration in wheat plants grown on the calcareous soil was increased by the application of $ZnCl_2$ and ZnEDTA fertilizers. However, ZnEDTA was more effective than $ZnCl_2$ in increasing plant Zn content. The concentration of Zn in the plant shoots usually increased with amount of Zn added for both

Table 2. Effect of Zn Fertilizer Treatment, Rate of Zn Applied and Size of Fertilizer Band on Shoot and Root Dry Matter Yield and Plant Zn Content

		Band Size 1 ($15.89\ cm^2$)			Band Size 2 ($32.15\ cm^2$)		
Zn Fertilizer	Rate of Zn Applied ($mg\ cm^{-2}$)	Shoot DM Yield ($g\ pot^{-1}$)	Root DM Yield ($mg\ cyl^{-1}$)	Shoot Zn Conc. ($\mu g\ g^{-1}$)	Shoot DM Yield ($g\ pot^{-1}$)	Root DM Yield ($mg\ cyl^{-1}$)	Shoot Zn Conc. ($\mu g\ g^{-1}$)
Control	0	38.0 a[1]	309 a	7.8 d	37.5 a	626 a	7.7 e
$ZnCl_2$	0.63	42.5 a	267 a	7.1 d	36.5 a	558 ab	8.4 e
	1.26	37.0 a	332 a	8.0 d	37.8 a	625 a	10.1 e
	2.52	40.7 a	290 a	9.3 d	39.4 a	540 ab	10.3 e
	5.03	40.3 a	326 a	9.7 cd	39.6 a	524 ab	12.0 de
ZnEDTA	0.63	38.5 a	256 a	12.4 c	40.3 a	522 ab	15.9 d
	1.26	38.0 a	259 a	17.3 b	37.2 a	539 ab	23.0 c
	2.52	36.8 a	295 a	18.8 b	37.7 a	511 ab	31.1 b
	5.03	37.5 a	294 a	27.8 a	38.9 a	403 b	39.7 a

[1] Tukeys Studentized Range.
Means with the same letter within a column are not significantly different ($P = 0.05$).

Table 3. Effect of Zn Fertilizer Treatment and Rate of Zn Applied on Shoot and Root Dry Matter Yield and Plant Zn Content

Zn Fertilizer	Rate[1] of Zn Applied (mg cm^{-2})	Shoot DM Yield (g pot^{-1})	Root DM Yield (mg cyl^{-1})	Shoot Zn Conc. ($\mu g\ g^{-1}$)
Control	0	19.5 a[2]	208 a	9.2 d
	0.16	16.8 a	135 ab	13.3 d
	0.63	16.5 a	118 ab	15.1 d
$ZnCl_2$	2.52	16.1 a	125 ab	14.6 d
	5.03	18.1 a	102 b	14.8 d
	10.06	16.5 a	84 b	21.8 dc
	0.16	17.4 a	125 ab	9.8 d
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ZnEDTA	2.52	19.3 a	162 ab	31.5 c
	5.03	15.8 a	92 b	46.4 b
	10.06	17.5 a	143 ab	69.0 a

[1] The Zn was applied as a band of an area 15.89 cm^2.

[2] Tukeys Studentized Range.
Means with the same letter within a column are not significantly different (P - 0.05).

Table 4. Effect of Zn Fertilizer Treatment and Rate of Zn Applied on Shoot and Root Dry Matter Yield and Plant Zn Content

Zn Fertilizer	Rate[1] of Zn Applied ($mg\ cm^{-3}$)	Shoot DM Yield ($g\ pot^{-1}$)	Root DM Yield ($mg\ cyl^{-1}$)	Shoot Zn Conc. ($\mu g\ g^{-1}$)
	0	40.3	362	10.7
	0.02	43.4	401	11.7
	0.05	41.0	388	13.3
	0.10	40.3	380	21.3
$ZnCl_2$	0.20	44.4	415	26.1
	0.40	40.5	507	45.2
	0.80	44.5	503	71.3
	1.60	43.3	287	86.3
	3.20	43.7	50	92.4
	0	40.3	362	10.7
	0.02	41.2	327	12.7
	0.05	42.3	294	12.2
	0.10	42.4	268	12.8
ZnEDTA	0.20	40.6	222	17.3
	0.40	42.2	172	22.4
	0.80	42.7	92	28.1
	1.60	41.5	102	47.5
	3.20	37.7	76	74.2

Significance (P - 0.01)

	Shoot DM Yield	Root DM Yield	Shoot Zn Conc.
Zn Source	NS	**	**
Rate	NS	**	**
Source x Rate	NS	**	**

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[1] Rates of Zn shown were thoroughly mixed in 200 g of soil (4% of total soil volume used in each pot).

fertilizers, but the increases were not statistically significant when the plants were treated with $ZnCl_2$. (Table 2). Plant Zn content was substantially increased by increasing the size of the fertilizer band, particularly when ZnEDTA was applied. This effect is quite evident from data in table 2 although a statistical evaluation of the effect of size of fertilizer band on plant Zn content was not conducted.

Both Zn fertilizers increased the concentration of Zn in the plant shoots, when they were applied to the slightly calcareous as well as the noncalcareous soils. (Table 3 and 4). However, some of the increases were not statistically significant. Zinc content of plants grown on the two soils increased with amount of Zn added. It is also quite evident from the results that when ZnEDTA was applied to the slightly calcareous soil Zn concentrations in the plant shoots were much greater than Zn contents of plants treated with $ZnCl_2$.

Results of Zn concentration in wheat plants grown on the noncalcareous soil show that at low rates of Zn application both Zn fertilizers were equally effective in supplying Zn to the plant (Table 4 and Fig 2.) However, in contrast to results obtained with the other two soils, $ZnCl_2$ was more effective than ZnEDTA in supplying Zn to the plants, at high rates of applied Zn. The concentration of Zn in plants treated with $ZnCl_2$ were much greater than Zn contents of plants treated with ZnEDTA. The large differences in plant Zn contents between the two Zn fertilizers when incorporated into a limited amount of soil may largely be attributed to the large differences in root growth in the two fertilizer bands. (Fig 1). The results clearly show that the amount of roots in the ZnEDTA fertilizer band was always much lower than the amount of roots in the $ZnCl_2$ fertilizer band except when the rate of Zn applied was very low or very high. As indicated before root quality was also significantly decreased for virtually all rates of Zn, applied to the noncalcareous soil as ZnEDTA. Therefore, the results suggest that although the concentration of Zn in the ZnEDTA fertilizer band was greater than the concentration of Zn in the $ZnCl_2$ fertilizer band, (Table 7), the amount of roots in the fertilizer band was a major factor affecting Zn uptake by the plants, i.e. the amount as well as the quality of roots in contact with the Zn fertilizer reaction zone was probably a more important factor determining the extent of Zn uptake from the fertilizer bands than the concentration of Zn in the bands. It should be noted however, that Zn uptake from the fertilizer bands also increased with amounts of Zn added for both Zn fertilizers suggesting that the concentration of Zn in the fertilizer bands is also an important factor affecting Zn uptake by plants.

Root Growth and Plant Zn Content in Relation to the Concentration of Zn in the Zn Fertilizer Bands.

The concentration was well as the forms of water soluble Zn in the Zn fertilizer bands for the soils used in the plant growth studies is presented in Tables 5, 6 and 7. The results clearly show that the concentration of Zn in the ZnEDTA fertilizer bands were remarkably greater than the concentrations of Zn in the $ZnCl_2$ fertilizer band for all the three soils, when both Zn fertilizers were applied at equivalent rates of Zn. Virtually all the Zn in the $ZnCl_2$ fertilizer bands existed in the ionic form while in the case of the ZnEDTA fertilizer bands some of the Zn in soil solution was in the complexed form. The total as well as the ionic forms of Zn in soil solution increased with amount of $ZnCl_2$ or ZnEDTA applied for all three soils. However, the proportion of the total amount of Zn that was in the ionic form in soils treated with ZnEDTA decreased with amount of ZnEDTA added except for the slightly calcareous soil in which the fraction of total water soluble Zn that was in the ionic form remained relatively constant with amount of ZnEDTA added.

The results also show that when $ZnCl_2$ was applied to the calcareous soil the concentration of Zn in the fertilizer band was significantly lower than the concentration of Zn in the fertilizer band when similar amounts of $ZnCl_2$ were applied to the slightly calcareous soil (Tables 5, 6). The low concentration of Zn in soil solution resulting from application of $ZnCl_2$ to the calcareous soil was probably caused by the high pH as well as presence of high amounts of $CaCO_3$ in the calcareous soil. According to Kalbasi et al (1978), the concentration of Zn in soil solution when inorganic Zn fertilizers such as $ZnCl_2$ or $ZnSO_4 \cdot 7H_2O$ were added to a calcareous soil was largely determined by the solubility of the reaction products formed. The main reaction products detected in calcareous soils were $ZnCO_3$ and/or $Zn(CO_3)_2(OH)_6$. The dominant reaction product detected in noncalcareous soils treated with inorganic Zn fertilizers was $Zn(OH)_2$. The solubility of these reaction products decreased substantially with significant increases in pH. No reaction products were detected in calcareous or noncalcareous soils treated with ZnEDTA. Therefore, the greater solubility of Zn in ZnEDTA fertilizer bands is probably attributed to the fact that a significant proportion of Zn applied as ZnEDTA remains complexed and likely not available to form insoluble reaction products with other soil constituents.

The results obtained in these studies show that the extent of root growth in the Zn fertilizer bands is a function of the Zn concentration in the fertilizer bands (Fig 3 and 4). Root growth in the fertilizer bands was not significantly affected when Zn concentrations in the fertilizer bands were relatively low. This was particularly evident when the Zn was incorporated into a

Table 5. Effect of Zn Fertilizer Treatment and Rate of Zn Applied on Total and Ionic Zn in Soil Solution

	$ZnCl_2$			ZnEDTA		
Rate of Zn Applied (mg cm^{-2})	Total Zn (μg ml^{-1})	Ionic Zn (μg ml^{-1})	(%)[1] of Total	Total Zn (μg ml^{-1})	Ionic Zn (μg ml^{-1})	(%) of Total
0	0.15	0.11	(73.3)	0.15	0.11	(73.3)
0.63	0.27	0.19	(70.4)	320	144	(45.0)
1.26	0.54	0.47	(87.0)	664	312	(48.4)
2.52	2.40	2.39	(99.6)	1256	504	(40.1)
5.03	33.0	32.98	(99.9)	2624	968	(36.9)

Almasippi Loamy Fine Sand

[1] ( ) Proportion of total amount of Zn in soil solution that was in the ionic form.

Table 6. Effect of Zn Fertilizer Treatment and Rate of Zn Applied on Total and Ionic Zn in Soil Solution

Rate of Zn Applied ($mg\ cm^{-2}$)	$ZnCl_2$			ZnEDTA		
	Total Zn ($\mu g\ ml^{-1}$)	Ionic Zn ($\mu g\ ml^{-1}$)	(%)[1] of Total	Total Zn ($\mu g\ ml^{-1}$)	Ionic Zn ($\mu g\ ml^{-1}$)	(%) of Total
0	0.08	0.07	(87.5)	0.08	0.07	(87.5)
0.16	0.40	0.36	(90.0)	49.2	2.0	(0.04)
0.63	0.73	0.68	(93.2)	280	16.0	(0.06)
2.52	24.0	23.9	(99.6)	1024	40.0	(0.04)
5.03	184.0	177.4	(96.4)	1752	48.0	(0.03)
10.06	648.0	630.8	(97.3)	3064	192.0	(0.06)

Willowcrest Fine Sand (Slightly Calcareous)

[1] ( ) Proportion of total amount of Zn in soil solution that was in the ionic form.

Table 7. Effect of Zn Fertilizer Treatment and Rate of Zn Applied on Total and Ionic Zn in Soil Solution

Rate of Zn Applied (mg cm^{-3})	ZnCl$_2$ Total Zn (μg ml^{-1})	ZnCl$_2$ Ionic Zn (μg ml^{-1})	ZnCl$_2$ (%)[1] of Total	ZnEDTA Total Zn (μg ml^{-1})	ZnEDTA Ionic Zn (μg ml^{-1})	ZnEDTA (%) of Total
0	0.04	0.02	(50.0)	0.04	0.02	(50.0)
0.02	0.09	0.07	(77.8)	23.0	15.6	(67.8)
0.05	0.25	0.22	(88.0)	66.4	30.0	(45.2)
0.10	0.50	0.48	(96.0)	192.0	80.0	(41.7)
0.20	2.20	2.00	(90.9)	378.0	128.0	(33.9)
0.40	13.2	11.00	(93.3)	776.0	172.0	(22.2)
0.80	120.0	112.50	(93.8)	1616.0	328.0	(20.3)
1.60	460.0	430.60	(93.6)	4240.0	720.0	(17.0)
3.20	1820.0	1720.00	(94.5)	6000.0	1040.0	(17.3)

Willowcrest Fine Sand (Noncalcareous)

[1] ( ) Proportion of total amount of Zn in soil solution that was in the ionic form.

limited amount of soil (Fig. 1). In fact slight root proliferation was evident when low rates of $ZnCl_2$ were added to the soil. In contrast, root growth in the fertilizer bands was significantly reduced when the levels of Zn in soil solution were very high, regardless of the form of Zn applied. In some cases ZnEDTA appeared to be more detrimental to root growth than $ZnCl_2$. Data in Figure 3 and 4 for example, clearly shows that in the presence of equal amounts of Zn in soil solution root growth in the $ZnCl_2$ fertilizer bands was always greater than root growth in the ZnEDTA fertilizer bands except at very low or very high amounts of Zn in soil solution.

Summary and Conclusions

Plant growth studies were conducted on two Willowcrest Fine Sand and one Almasippi Loamy Fine Sand soils, to determine the effect of $ZnCl_2$ and ZnEDTA fertilizer bands on root growth and Zn uptake by wheat. $ZnCl_2$ had no significant effect on the amount of roots recovered from the fertilizer band, when it was applied to the Almasippi soil. On the other hand root growth in the $ZnCl_2$ fertilizer band was reduced by virtually all rates of Zn when applied to the slightly calcareous Willowcrest soil. Incorporation of low rates of $ZnCl_2$ into a limited amount of the noncalcareous Willowcrest soil resulted in a considerable root proliferation in the fertilizer band, reaching a maximum at about the 0.6 mg cm^{-3} rate. Rates of Zn greater than 0.8 mg cm^{-3} resulted in significant reductions in root growth in the fertilizer band. ZnEDTA reduced root growth in the ZnEDTA fertilizer bands in all three soils.

Root growth in the fertilizer bands was closely related to the concentration of Zn in the fertilizer bands. The amount of roots as well as the quality of roots recovered from the fertilizer bands was significantly decreased by high concentrations of Zn in the fertilizer band for both Zn fertilizers. Although Zn uptake generally increased with concentration of Zn in the fertilizer bands, the results obtained in this study suggest that root growth in the fertilizer bands was probably the major factor affecting Zn uptake from the bands. Therefore, it can be concluded from the results of these studies that when Zn is applied as fertilizer bands, the concentration of water soluble Zn in the fertilizer bands can be substantially high. As a result, root growth and therefore Zn uptake from the site of application is severely limited.

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Fig 1. Effect of Zn Fertilizer Treatment and Rate of Zn Applied on Root DM Yield

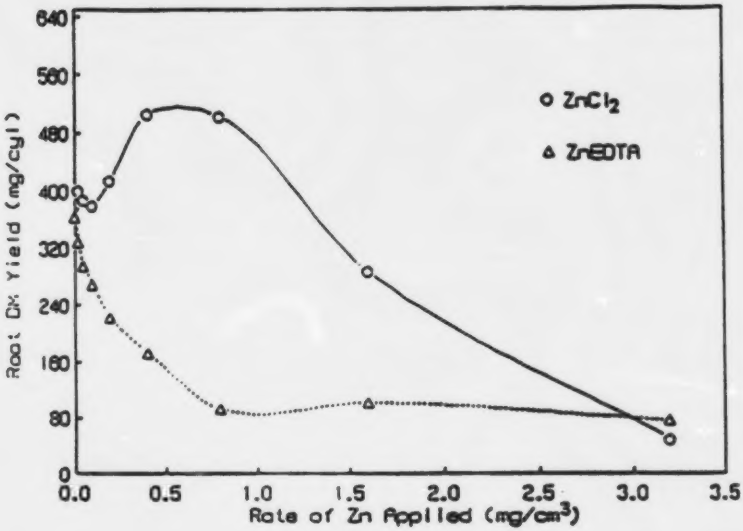


Fig 2. Effect of Zn Fertilizer Treatment and Rate of Zn Applied on Plant Zn Content

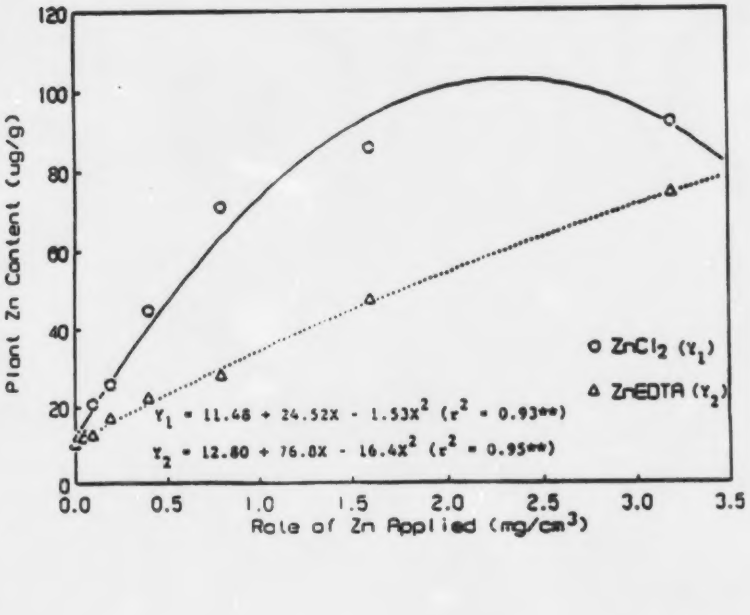


Fig. 3 Effect of Total Amount of Zn in Soil Solution on Root DM Yield

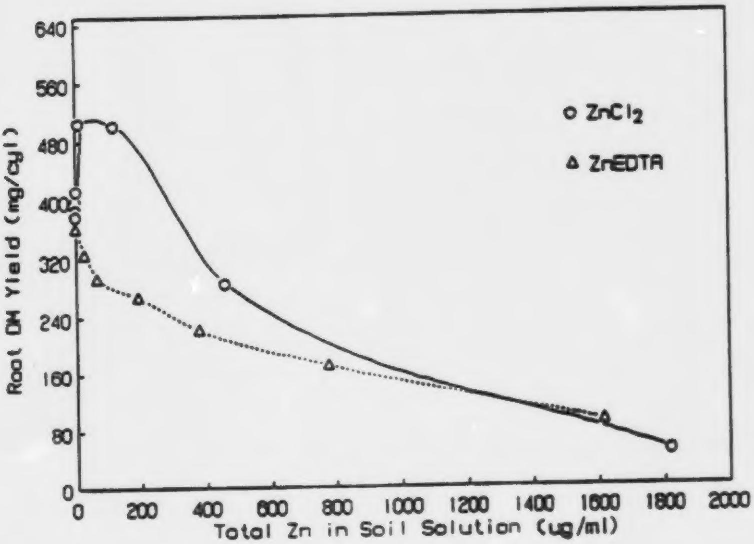
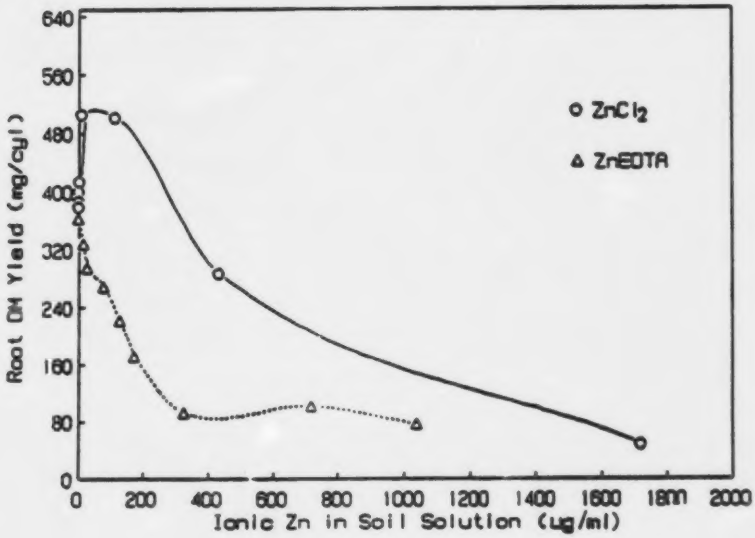


Fig. 4 Effect of Amount of Ionic Zn in Soil Solution on Root DM Yield



Phosphorus and Zinc Fertilization and Their Residual Effects in Canola - Wheat and Barley - Wheat Rotations

Shihua Tu and Tee Boon Goh
Department of Soil Science
University of Manitoba, R3T 2N2

Phosphorus and Zn fertilization and their residual effects on crops were investigated on an Almasippi sandy loam soil with two different rotations: canola—wheat and barley—wheat. The experiment was conducted by using a completely randomized split-split plot design. P, as the main factor with three rates(0, 100, 250 kg/ha), was added in the first year; Zn, as the subplot factor with two rates(0, 20 kg/ha and 0, 10 kg/ha respectively), was split in the first and second year; N and K were added in both years as basal fertilizers. The results revealed that both barley and canola showed significant response to added P, but only canola had high sensitivity to low level of soil Zn(0.7 mg Zn/kg) and hence significantly responded to added Zn. In the second year, P on barley stubble had pronounced residual effect on wheat grain yield but not on canola stubble. In relation to Zn it seemed that Zn addition was required in the second crop only when continuous cereals were practiced and no Zn was added in the first year. Zn fertilization enhanced P concentration and uptake in the plant in most cases; while the effects of added P on Zn concentration and uptake were complicated in this experiment. The intriguing residual effect of P and Zn on different rotations may be ascribed to different root systems and nutrient absorption characteristics between barley and canola.

Introduction

Numerous studies have been carried out on the interaction between P and Zn. It is well known that after heavy dressing of P fertilizer to a soil or in a soil containing high levels of available P, the symptoms of Zn deficiency tend to occur in the plant and even can be aggravated in soils that are low or marginal in available Zn. Several hypotheses have been proposed to interpret the P-induced Zn deficiency including interaction of P with Zn in the soil; a lower rate of translocation of Zn from roots to tops; a simple dilution effect on Zn concentration in the top owing to the growth response to P and a metabolic disorder with plant cells related to imbalance between P and Zn (Olsen et al., 1972). Some other investigators (Loneragan et al., 1982; Cakmak and Marchner, 1986), however, suggested that P-induced Zn deficiency was attributed to accumulation of P to toxic levels in the leaves inducing symptoms resembling Zn deficiency.

Yet, conflicting reports often occurred. Boawn et al. (1954) and Ellis et al. (1964) reported that they failed to induce Zn deficiency in corn and beans (Phaesolus vulgaris) even where P contents in the plant were doubled. The research by Orabi et al. (1981-1982) showed the existence of positive relationship between Zn uptake and P-uptake by corn plants. Therefore, several other investigators ascribed the discrepancy to the facts that crops or species differ in their susceptibility to P-induced Zn deficiency in soil (Amber and Brown, 1969; Brown and Tiffin, 1962; Burleson et al., 1961; Shukla and Raj, 1987) and in their feeding power for Zn (Gladstones and Loneragan, 1967; Bowen, 1987). But little is known about the effect of rotation on P x Zn interaction. Therefore, this present study was designed to further clarify P x Zn interaction in different crops and the effect of rotations on the interaction.

Materials and Methods

The experiment was conducted on an Almasippi soil with sandy loam texture, pH 8.0, $NaHCO_3$ extractable P 2.7 mg/kg, DTPA extractable Zn, Cu and Mn 0.7, 0.45 and 10.2 mg/kg respectively. The rotations were established with three crops, barley (Bonanza) and canola (Westar) in 1987 and wheat as the following crop in 1988. The study was carried out by using a completely randomized split-split plot design with four replicates. P, as the main factor with three rates(0, 100, 250 kg/ha), was added in the first year; Zn, as the subplot factor with two rates (0, 20 kg/ha and 0, 10 kg/ha respectively), was split in the first and second year; N and K were added in both years as basal fertilizers. All the fertilizers were broadcast except Zn which was sprayed. The plots were plowed after fertilization in 1987 and zero tillage was practiced in 1988.

Plant samples were taken at heading stage and maturity for cereals and at pod stage and maturity for canola. After air-drying, yields of the shoots and the grain were measured and then ground to < 2 mm mesh in a Thomas-Wiley mill. The digestion was performed in a perchloric-nitric acid mixture (Bowen, 1967; Champman & Pratt, 1961). Concentration of P in the plant tissue was determined by the molybdate-blue method (Murphy & Riley, 1962) and those of Zn, Cu, Mn and Fe were analyzed by atomic absorption spectroscopy.

Soil samples were taken before seeding in both years. Soil P was determined by using $NaHCO_3$ extraction (Olsen et al., 1954, Murphy & Riley, 1962) and Zn, Cu, Mn and Fe by DTPA extraction (Follet & Lindsay, 1971).

Results and Discussion

Results in 1987

In 1987, in spite of low level of soil available Zn, neither barley straw nor grain yield showed significant response to added Zn but only to added P (Fig. 1). Canola, on the other hand, was more sensitive to Zn nutrition and hence significantly responded to added Zn. Without application of Zn seed yield did not increase regardless of amount of P added (Fig. 2). Phosphorus increased the seed yields only when both Zn and P were applied, indicating that Zn deficiency was a limiting factor to canola production on this soil.

The metabolic requiremnet for P and Zn were obviously different between the two crops. Canola accumulated higher concentration of P and Zn in the tops compared with barley even when its seed yield was limited by lower soil available Zn (Tables 1 and 2). This is in good agreement with the findings by Strong and Soper (1974) that canola had the strongest absorption ability for P among the four tested crops,

Fig. 1. BARLEY GRAIN YIELD AS AFFECTED BY P AND Zn APPLICATION IN 1987

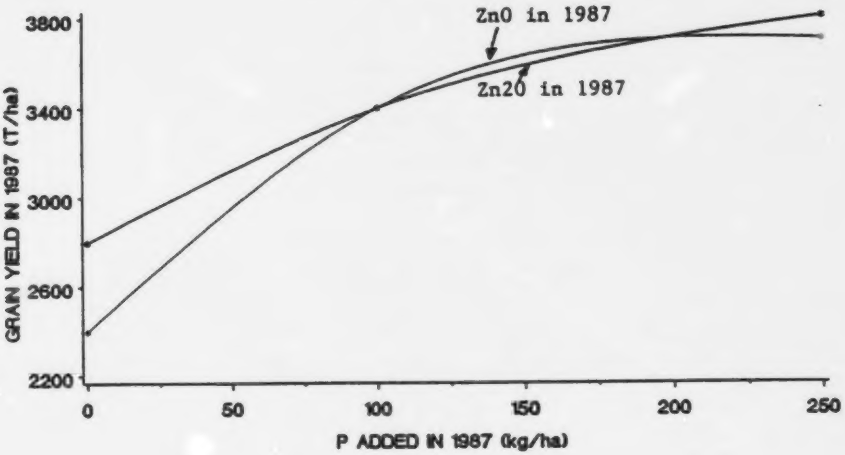
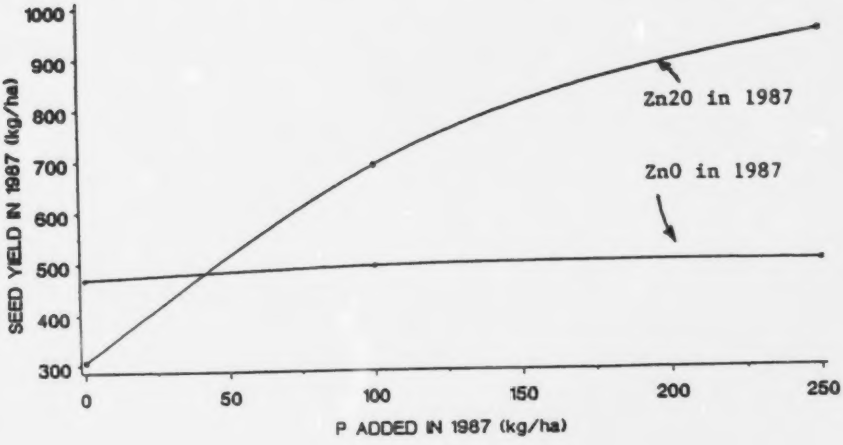


Fig. 2. CANOLA SEED YIELD AS AFFECTED BY P AND Zn APPLICATION IN 1987



flax, wheat, canola and buckwheat under the condition of added or non-added P, and with the observation by Safaya and Singh (1977) that the variety of cowpea more susceptible to Zn deficiency was found to have higher Zn concentration in its shoots. In other word, a species or cultivar with high demand on a certain nutrient requires high supply of the nutrient in the soil or medium. Consequently we can deduce that different crops or cultivars have different critical values for a given nutrient in both soil and plant tissues. The high efficiency of utilizing soil P and Zn by canola is attributed to its high rooting density and its ability to secrete solubilizing agent, such as H^+, from root surface when the soil is P deficient (Nye, 1984), which is of importance especially in calcareous soils. In some soil the solubilized P by canola can reach an extent that is available to the subsequent crops in the rotation.

Table 1 P Concentration (g.kg^{-1}) in Barley and Canola As affected by P and Zn Application (1987)

Crop	Zn added (kg.ha^{-1})	P added (kg.ha^{-1})					
		0	100	250	0	100	250
			Straw			Grain	
Barley	0	0.6	0.8	1.5	2.4	4.4	4.6
	20	0.6	0.9	1.1	2.8	4.6	5.0
			LSD$_{.05}$ = 0.2			LSD$_{.05}$ = 0.3	
			Shoot			Seed	
Canola	0	0.8	1.7	2.0	6.0	8.8	9.1
	20	0.9	1.7	1.8	6.9	8.5	8.4
			LSD$_{.05}$ = 0.3			LSD$_{.05}$ = 0.5	

Table 2 Zn Concentration (mg.kg^{-1}) in Barley and Canola As affected by P and Zn Application (1987)

Crop	Zn added (kg.ha^{-1})	P added (kg.ha^{-1})					
		0	100	250	0	100	250
			Straw			Grain	
Barley	0	13	6	5	32	24	23
	20	30	20	18	43	43	41
			LSD$_{.05}$ = 3			LSD$_{.05}$ = 3	
			Shoot			Seed	
Canola	0	15	9	10	45	43	37
	20	34	17	11	51	50	45
			LSD$_{.05}$ = 3			LSD$_{.05}$ = 3	

As shown in Tables 1 and 2, added P significantly decreased Zn concentration in both crops, while added Zn depressed P contents only in canola, showing an antagonistic relationship between Zn and P contents in the canola plant. Even so the total uptake of P by both crops was enhanced by addition of Zn (Table 3). Uptake of Zn, on the other hand, was reduced by increased P in canola but increased with increased P in barley when both Zn and P were applied, indicating a different interaction of P x Zn in different crops.

Table 3 P Uptake ($kg.ha^{-1}$) and Zn Uptake ($g.ha^{-1}$) in Barley and Canola Tops As affected by P and Zn Application (1987)

Crop	Zn added ($kg.ha^{-1}$)	P added ($kg.ha^{-1}$)					
		0	100	250	0	100	250
		P Uptake			Zn Uptake		
Barley	0	8.1	18.5	26.6	123	109	122
	20	9.4	22.5	30.7	206	271	261
			$LSD_{.05} = 2.5$			$LSD_{.05} = 20$	
		P Uptake			Zn Uptake		
Canola	0	6.1	14.2	17.6	83	73	76
	20	5.2	16.8	21.5	143	141	122
			$LSD_{.05} = 4.0$			$LSD_{.05} = 25$	

Nutrient Status after the First Year Cropping

Soil samples were taken in May, 1988, and the pertinent nutrients were analyzed as shown in Tables 4-1, 4-2 and 5. The data indicated that DTPA extractable Zn of the soil was independent of the amount of P added in the previous years on either canola or barley stubble. Several workers also observed no changes in the soluble Zn or Zn intensity in the soil solution with low to high rates of applied P (Bingham and Garber, 1960; Stukenholtz et al., 1966; Brown et al., 1970; Pasricha et al., 1987). Therefore it is unlikely that P-induced Zn deficiency is due to the formation of Zn_3PO_4 precipitate in the soil, which proved to be a good source of fertilizer of Zn (Boawn et al., 1957; Allen and Terman, 1966).

Table 4-1 Soil Nutrient Status after the First Year Cropping On Two Stubbles before Seeding in 1988

Stubble	Zn added ($kg.ha^{-1}$)	Nutrient Concentration ($mg.kg^{-1}$)					
		P			Zn		
		P added ($kg.ha^{-1}$)					
		0	100	250	0	100	250
Canola	0	7.3	21.1	50.4	0.88	0.90	0.84
	20	8.1	18.4	50.2	5.40	4.28	4.47
		$LSD_{.05}$ =3.5			$LSD_{.05}$ = 0.76		
Barley	0	6.3	21.3	50.1	0.78	0.84	1.11
	20	7.0	29.5	59.5	4.15	4.79	4.42
		$LSD_{.05}$ =4.6			$LSD_{.05}$ = 0.69		

Table 4-2 Soil Nutrient Status after the First Year Cropping On Two Stubbles before Seeding in 1988

Stubble	Zn added ($kg.ha^{-1}$)	Nutrient Concentration ($mg.kg^{-1}$)					
		Cu			Mn		
		P added ($kg.ha^{-1}$)					
		0	100	250	0	100	250
Canola	0	1.02	1.00	1.00	12.3	15.7	12.2
	20	0.94	1.00	1.02	12.3	18.6	10.8
		$LSD_{.05}$ =0.20			$LSD_{.05}$ =1.8		
Barley	0	0.50	0.58	0.80	11.7	13.1	15.8
	20	0.56	0.75	0.88	12.6	13.9	15.0
		$LSD_{.05}$ =0.09			$LSD_{.05}$ = 1.8		

Table 5 The Average Soil Nutrient Contents after the First Year Cropping before Seeding on Two Stubbles (1988)

Stubble	Nutrient Concentration (mg.kg^{-1})			
	P	Zn	Cu	Mn
Canola	25.9 b	2.8	0.97 a	13.7
Barley	28.9 a	2.7	0.68 b	13.7

Added Zn did not markedly affect NaHCO$_3$ extractable P on canola stubble but did cause significant increase of P on barley stubble. Concentrations of DTPA extractable Cu and Mn on the barley stubble were significantly increased by both P and Zn added. Cu concentration did not change on canola stubble, while Mn concentration reached the highest value at P100 and then dropped to the lowest points at P250 (table 4-2). It is apparent that rotations appreciably affected the status of extractable nutrients in the soil. But little is known about why and how this occurred.

Plant Growth in 1988

Field observation, since the early growth stages had clearly showed that wheat growth was much better on the canola stubble than on the barley stubble. At heading stage the top dry matter yield on the canola stubble was usually about one and half times higher than on barley stubble (Table 6).

Table 6 Wheat Top Yield (kg.ha^{-1}) at Heading Stage on Two Rotations As Affected by Applied P and Zn (1988)

Stubble	Zn added (kg.ha^{-1}) in 1987	Zn0 in 1988			Zn10 in 1988		
		P Added in 1987 (kg.ha^{-1})					
		0	100	250	0	100	250
Canola	0	1025	1133	1293	1118	1313	1238
	20	1070	1155	1588	1025	1373	1695
		LSD$_{(p)}$·05 = 34			LSD$_{(Zn)}$·05 = 44		
Barley	0	735	1113	700	885	765	1030
	20	730	778	890	850	863	908
		LSD$_{(p)}$·05 = 43			LSD$_{(Zn)}$·05 = 33		

Table 7 Wheat Grain Yield (kg.ha^{-1}) at Maturity on Two Rotations As Affected by Applied P and Zn (1988)

Crop	Zn added (kg.ha^{-1}) in 1987	Zn0 in 1988			Zn10 in 1988		
		P Added in 1987 (kg.ha^{-1})					
		0	100	250	0	100	250
Canola	0	2330	2600	2350	2200	2230	2380
	20	2250	2350	2035	2500	2500	2780
		$LSD_{(p)}\cdot05 = 532$			$LSD_{(Zn)}\cdot05 = 649$		
Barley	0	1080	1580	1580	1480	1850	2350
	20	1000	1630	1730	1550	1700	2050
		$LSD_{(p)}\cdot05 = 433$			$LSD_{(Zn)}\cdot05 = 495$		

The average top dry matter yield of wheat was 851 and 1245 kg/ha on barley and canola stubbles respectively. At maturity the grain yields on the canola stubble always exceeded those on the barley stubble (Table 7), indicating the beneficial effect of canola on its following crops. The differences in plant growth and grain yield between rotations might be ascribed to a so-called allelopathic effect. Early in 1966, Overland found that barley inhibited seed germination and the growth of selected plant species, involving inhibitory substance or substances secreted from barley roots or from decomposition of its residues, as well as the allelochemical compounds released from microorganisms. Canola, however, stimulated the growth of a subsequent wheat crop seedlings (Martin and Rademacher, 1960). Harper and Lynch (1982) compared allelopathic effect of four crop straws, wheat, barley, oat and rape. They found that removal of water soluble components did not significantly change acetic acid production from cereal straws but halved the production from rape straw, demonstrating that the dominant components of cereal straws are water-insoluble and hence responsible for the lasting toxicity to the subsequent crops during their decomposition processes by soil microorganisms. In the present study, canola promoted whereas barley inhibited the following crops.

Nutrient Contents in the Plant Tissues

From heading to maturity, total uptake of all the nutrients measured in the tops remained consistently significantly higher on the canola stubble except Cu (Tables 8 and 9), although the concentration of $NaHCO_3$ extractable P was significantly lower and DTPA extractable Zn higher in the soil before seeding on the canola stubble compared to that on the barley stubble (Tables 4 and 5). This suggests that P on canola stubble may form as available but non-extractable compounds or some other unidentified substances related to canola may exist to stimulate P uptake by the crop.

Table 8 The Average Top Yield and Nutrient Uptake by Wheat at Heading Stage after the First Year Cropping on Two Stubbles (1988)

Stubble	Top yield	Nutrient Uptake $(g.ha^{-1})$				
	$(kg.ha^{-1})$	P*	Zn	Cu	Mn	Fe
Canola	1245 a	26.8 a	5.6 a	0.39 a	2.6 a	34.8 a
Barley	850 b	19.4 b	3.6 b	0.35 a	1.7 b	28.8 b

P*— P uptake $(kg.ha^{-1})$

Table 9 The Average Grain Yield and Nutrient Uptake by Wheat at Maturity in the Second Year Cropping on the Two Stubbles (1988)

Stubble	Yield $(kg.ha^{-1})$		Nutrient Uptake $(g.ha^{-1})$				
	Top	Grain	P*	Zn	Cu	Mn	Fe
Canola	6000 a	2400 a	11.3 a	202.7 a	8.3	55.9 a	311.2 a
Barley	420 b	1630 b	7.6 b	163.0 b	8.8	35.6 b	255.1 b

P*—P uptake $(kg.ha^{-1})$

In relation to the nutrient concentration and uptake in the plant as affected by P and Zn fertilization, the added P in 1987 resulted in significant increase in concentration and uptake of P in the plant in 1988 only when compared with P0 (Table 10). However, whether Zn was added in 1987 or in 1988, the concentration and uptake of P in the plant tissues were not different on either stubble (Table 10).

Table 10 P Concentration $(g.kg^{-1})$ in the Plant Tissues at Maturity As Affected by Applied P and Zn and Rotations (1988)

Stubble	Zn added $(kg.ha^{-1})$ in 1987	Zn0 in 1988			Zn10 in 1988		
		P Added in 1987 $(kg.ha^{-1})$					
		0	100	250	0	100	250
				Straw			
Canola	0	0.40	0.49	0.51	0.35	0.41	0.46
	20	0.31	0.53	0.47	0.38	0.51	0.45
				LSD$_{.05}$ = 0.12			
				Grain			
	0	3.1	4.8	4.2	3.6	4.5	4.1
	20	4.0	4.6	4.2	3.8	4.2	4.5
				LSD$_{.05}$ = 0.9			
				Straw			
Barley	0	0.38	0.52	0.63	0.32	0.52	0.54
	20	0.41	0.46	0.55	0.43	0.49	0.47
				LSD$_{.05}$ = 0.12			
				Grain			
	0	2.7	5.1	4.8	2.7	4.4	3.5
	20	3.9	4.2	4.3	3.5	4.3	4.6
				LSD$_{.05}$ = 1.4			

Addition of Zn significantly enhanced concentration and uptake of Zn in the plant regardless of the year when it was added (Table 11). Applied P in 1987, on the other hand, depressed Zn concentration and uptake in the plant on canola stubble but surprisingly enhanced Zn concentration and uptake on barley stubble (Table 11). This is of great interest and importance for us to understand the interactions of P x Zn in the plant. It may shed a light upon the numerous contradictory reports on the interaction that the experiments failed to produce repeated results. The results suggest that different rotations change availability of certain nutrients and their interactions in the soil and within the crop, thus stimulating or inhibiting the nutrient uptake and plant growth.

Table 11 Zn Concentration ($mg.kg^{-1}$) in the Plant Tissues at Maturity As Affected by Applied P and Zn and Rotations (1988)

Stubble	Zn added ($kg.ha^{-1}$) in 1987	Zn0 in 1988			Zn10 in 1988		
		P Added in 1987 ($kg.ha^{-1}$)					
		0	100	250	0	100	250
		Straw					
Canola	0	14.3	13.1	15.5	16.0	14.5	15.8
	20	29.9	22.8	23.5	33.5	27.9	22.8
		$LSD_{.05}$ = 6.2					
		Grain					
	0	68.6	42.3	34.1	60.2	47.4	28.4
	20	72.5	62.5	58.5	76.0	59.8	54.9
		$LSD_{.05}$ = 12.3					
		Straw					
Barley	0	12.9	17.3	31.4	21.2	21.5	32.3
	20	29.8	30.9	44.0	34.0	41.4	48.1
		$LSD_{.05}$ = 7.4					
		Grain					
	0	47.5	58.5	36.3	57.1	41.0	47.1
	20	63.6	56.4	55.3	60.9	66.0	53.5
		$LSD_{.05}$ = 11.8					

In conclusion, canola shows response to Zn fertilization in Almasippi soil and needs higher tissue Zn concentration for the "normal" metabolism. Compared with barley, canola stubble benefits nutrient uptake by its following crop and growth as well. The different rotations affect interaction of P x Zn both in the soil and within the plant, namely, added Zn depressed extractable P in the soil on canola stubble but increased on barley stubble, and added P decreased Zn concentration in the wheat plant on canola stubble but increased on the barley stubble.

Acknowledgement

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UREA DISCER PROJECT

R. Siemens
Regional Agronomist
Manitoba Agriculture

INTRODUCTION

In 1986 the Agassiz Soil & Crop Improvement Association received funding through the Agri-Food project to place demonstration plots to determine the upper safe levels of using urea fertilizer with a discer seeder. The Manitoba Crop Production Guide has set an upper limit of 20 lbs. of urea nitrogen for a double run drill on cereal grains and are using these same recommended upper limits for a discer seeder. This recommendation was largely based on research done at the University of Manitoba which showed this to be a relatively safe limit for a double run drill. A large percentage of the cereal crops seeded on clay soils in the Red River Valley are seeded with a discer.

Farmers have been using higher rates of urea nitrogen in their discer seeders in order to cut their workload and eliminate the time consuming job of fertilizer application and incorporation. They pointed out the need for recommendations for upper limits of urea nitrogen with a discer seeder. Therefore the association felt it was important to initiate this project.

METHOD

To eliminate as many variables as possible, registered Katepwa wheat was purchased and used in all the plots. A Co-op discer was rented each year and used on all plots. The same fertilizer settings and plot design was used on each plot. Some changes in plot design were made in the first three years.

A replicated design was not possible because of complicated procedures when seeding with a discer seeder.

In 1986 plots were established on clay and clay loam soils. In order to eliminate a special blend for each treatment, 25 lbs. of P_2O_5 was mixed with the seed and the seeding rate set to 1 1/2 bushels of wheat and 25 lbs. of P_2O_5 per acre. The treatments consisted of: check, 31, 48, 56 and 81 lbs. of urea nitrogen. Each plot was top-dressed with urea nitrogen to bring the amount of nitrogen applied on all plots to 81 lbs. The urea was harrow incorporated immediately after seeding. Ten 1/4 M^2 plant counts were taken and 10 M^2 plots were harvested.

In 1987 we included a sandy loam soil and changed the design to include the following treatments: check, 95 lbs., check, 65 lbs., check, 31 lbs. Fifteen 1/4 M^2 plant counts were taken at the 3-4 leaf stage and ten M^2 samples were harvested for every plot. The seeding and fertilizer application rates and methods were the same as in 1986.

Soils were analyzed for their Cation Exchange Capacity levels and were - Lachance 38.2, Rattai 24.1, Horosko 12.5 and Gould 39.9.

The results were analyzed. None of the trends in germination or yield were statistically significant due to high field variability.

The treatments in 1988 were: check, 35 lbs., check, 85 lbs., check, 65 lbs., check. Twenty 1/4 M^2 plant samples and ten M^2 yield samples were taken from each plot.

RESULTS

1986

Four plots were established - three on clay and one on clay loam texture. Soil moisture was fair to good in spring and we received 151 - 216 mm of rain during the growing season.

TABLE I
1986 Soil properties and moisture conditions.

	Texture	% Soil * Moisture 0-36"	NO_3 (kg/ha)* Total	Rainfall Total (mm)
Roeland	clay	41.6	31	216.0
Lachance	clay	25.6	15	151.5
Rattai	clay loam	25.0	17	214.0
Dudich	clay	37.0	14	209.5

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*taken at time of seeding

Table II shows that there was considerable variability in plant counts between treatments.

TABLE II
1986 Plants /M/4

Treatment*	0	31	48	56	81
Roeland	70.3	71.8	73.3	73.3	65.7
Lachance	47.4	40.6	43.6	44.6	32.7
Rattai	59.5	40.5	49.8	53.0	45.0
Dudich	51.7	49.0	43.8	50.0	34.7

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*lbs. urea nitrogen applied with the seed.
All plots were top-dressed to 81 lbs. of urea nitrogen/acre.

The Roeland farm which had a very good soil moisture at time of seeding showed a decrease of 5 plants or 7% M/4 between the check treatment and the one receiving 81 lbs. of urea nitrogen with the seed. Three plots, Lachance, Rattai and Dudich showed a decrease of 31%, 24% and 33% respectively. Two of these plots were dry at time of seeding.

The plant stands appeared to be negatively affected at the high urea nitrogen levels but the yields were not. Table III shows that there was variability of yield between plots.

TABLE III
1986 Yield Bushels/Acre

Treatment*	0	31	48	56	81
Roeland	34.20	27.50	31.37	33.01	35.39
Lachance	33.60	27.56	31.82	30.63	36.13
Rattai	29.14	24.08	33.01	21.11	24.08
Dudich	28.10	33.30	32.86	29.44	33.60

----

*lbs. urea nitrogen applied with the seed.
All plots were top-dressed to 81 lbs. urea nitrogen/acre.

In comparing the yield between the check and the 81 lb. treatment we see that the Rattai plot had a decrease of 5.06 bushels/acre. The Roeland, Lachance and Dudich plots had an increase of 1.19 bushels, 2.53 bushels and 5.5 bushels/acre respectively.

1987

Soil moisture (Table IV) at time of seeding was quite dry especially in the top 15 cm. and remained dry during the month of June.

TABLE IV
1987 Soil properties and moisture conditions.

	Texture	% Soil Moisture 0-6"	% Soil Moisture 6-24"	NO_3 (kg/ha)* Total	Rainfall Total (mm)
Lachance	clay	21.5	26.6	31	322.0
Horosko	sandy loam	17.8	11.8	102	273.0
Rattai	clay loam	13.5	23.9	20	283.0
Gould	clay	16.3	27.4	186	246.0

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*taken at time of seeding

Under these conditions we had a decrease of plant count (Table V) of 21 to 67% per M/4 when the 95 lb. treatment is compared with the two neighboring check plots. At the 65 lb. rate three of the four plots showed a marked decrease ranging from 18-36%. At the 31 lb. rate only the sandy loam textured field showed a decrease in plant count.

TABLE V
1987 Plants /M/4

Treatment*	0	95	0	65	0	35
Lachance	38.10	29.60	37.10	38.20	41.50	40.60
Horosko	31.50	11.50	37.60	21.20	28.90	24.10
Rattai	44.80	30.80	35.80	30.80	39.60	41.10
Gould	34.20	22.80	33.50	23.50	35.10	30.60

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*lbs. urea nitrogen applied with the seed.
All plots were top-dressed to 95 lbs. of urea nitrogen/acre.

We received good moisture in early July at time of tillering and some of the treatments made noticeable recovery. However we still had a decrease in yield ranging from 8.5 to 28.5% at the 95 lb. treatment rate (Table VI) when compared to the two neighboring checks.

TABLE VI
1987 Yield Bushels/Acre

Treatment*	0	95	0	65	0	35
Lachance	44.01	40.15	43.72	37.03	46.39	43.42
Horosko	23.64	18.74	21.41	19.63	21.71	19.03
Rattai	31.08	21.56	29.74	24.24	23.94	21.71

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*lbs. urea nitrogen applied with the seed.
All plots were top-dressed to 95 lbs. of urea nitrogen/acre. The Gould plot was not harvested due to weed competition.

Under similar comparison the 65 lb. treatment had decreases in yield ranging from 8 to 17.8%. At the 31 lb. treatment we had decreases of 2.2 - 3 bushels per acre when compared to one check.

The results were analyzed in 1987. None of the trends in germination or yield were statistically significant due to the high field variability.

1988

Soil moisture at time of seeding was fair to good. Table VII shows that three of the four plots appear to be adversely affected by the 95 lb. treatment when compared with the neighboring checks. Plant population decreases ranged from 16.5 plants per M/4 (41%) on the sandy loam plot at Horosko to a 12 plant (16%) decrease on the clay loam plot at Rattai.

Table VII

1988 Plants M/4

Treatment*	0	35	0	85	0	65	0
Horosko	43.70	36.25	42.90	22.75	35.75	34.60	40.90
Rattai	77.00	75.40	75.00	63.70	75.90	68.00	75.70
Lachance	84.15	78.25	79.55	77.05	79.55	83.20	86.35
Morz	71.40	66.10	67.80	52.05	68.05	60.8	68.65

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*lbs. urea nitrogen applied with the seed.
All plots were top-dressed to 85 lbs. of urea nitrogen/acre.

With the 65 lb. treatment three plots showed a decrease of 3.7, 7.8 and 8 plants per M/4. This was a decrease of about 10% in each plot.

In 1988 the plots were under considerable heat and some drought stress during the growing season. The Horosko field was very poor and the yield samples were increased to two square meters per sample.

Table VIII
1988 Yield Bushels/Acre

Treatment*	0	35	0	85	0	65	0
Horosko	14.79	19.90	15.76	20.89	19.25	21.33	26.60
Rattai	53.78	62.10	65.96	49.13	50.58	50.24	51.51
Lachance	38.23	36.26	34.72	44.00	39.78	38.89	34.88

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*lbs.urea nitrogen applied with the seed.
All plots were top-dressed to 85 lbs. of urea nitrogen/acre.
The Morz plot was not harvested due to weed competition.

The yield variability on this field would correspond to moisture availability. The Rattai and Lachance plots did not appear to be affected by the 85 lb. treatment. In the Rattai plot the 85 lb. treatment yield was similar to three of the four checks and in the Lachance plot there was a seven bushel (18.9%) increase over the average of the checks.

OBSERVATION

High rates of urea nitrogen can affect germination. The amount of damage appears to be effected by soil moisture at time of seeding and by soil texture. In years of adequate soil moisture the decrease in plant counts will be less and may not affect yield. Lighter textured soils are more likely to be damaged by increased rates of urea nitrogen.

EFFECT OF NITROGEN, WATER AND PREVAILING CLIMATIC CONDITIONS ON YIELD AND QUALITY OF STUBBLED-IN WINTER WHEAT

M.H. Entz and D.B. Fowler

Department of Plant Science
University of Manitoba

and

Crop Development Centre
University of Saskatchewan

ABSTRACT

Nitrogen and water are important variables that influence both grain yield and quality of wheat. The present study was conducted to investigate the combined effects of N and water on the growth, water use, yield and grain protein concentration of winter wheat in Saskatchewan. Seven field experiments were conducted between 1984 and 1986 on a range of soil types. Irrigation to approximately 130% normal growing season precipitation significantly increased grain yield in all seven trials. In trials were residual soil NO_3-N to 61 cm averaged 40 kg ha^{-1}, a significant portion of the grain yield increase (from 2192 to 3330 kg ha^{-1}) was attributed to the interaction between water and fertilizer N. Increases in grain yields due to N and water were attributed to increased levels of pre-anthesis dry matter, a higher number of kernels m^{-2} and a higher water use efficiency (kg ha^{-1} grain mm^{-1} total crop water use). The semidwarf cultivar 'Norwin' and the tall 'Norstar' responded similarly to fertilizer N additions. In one trial, where moisture conditions were very favorable, a water x cultivar interaction indicated a greater response of Norwin to irrigation. The Gompertz equation was used to describe grain protein concentration-N response ($p \leq 0.01$). The coefficient that describes the initial lag phase of this function was correlated with dry matter at anthesis ($r=0.97^{**}$) and root zone extractable water at stem elongation ($r=0.85^{*}$). These results suggested that as pre-anthesis growing conditions improved, more N was required to produce an increase in grain protein concentration above a minimum 8.2%.

INTRODUCTION

Grain yield of stubbled-in winter wheat in the Canadian prairie region is limited primarily by available water and nitrogen. Most stubble fields are deficient in soil N (Fowler et al. 1989a) with the result that N fertilization is usually required to maximize yield. The importance of available water to yield of dryland wheat has also been documented (Campbell et al. 1977b; French and Schultz 1984; Entz and Fowler 1988) and in many instances the combined effects of water and nitrogen exceed the sum of their individual effects (Campbell et al. 1977a; Prihar et al. 1985; Henry et al. 1987).

Nitrogen and water are also important in determining grain quality. In Saskatchewan, soil N deficiencies with stubbled-in winter wheat have resulted in low grain protein concentrations, often less than 11% (Fowler et al., 1989b). Increased water availability can also lower protein concentration (Terman et al. 1969; Smika and Greb 1973). Therefore, in order to maintain a minimum grain protein concentration, higher levels of available water must be accompanied by increase in the levels of available N (Bole and Dubetz 1986; Henry et al. 1987; Fowler et al. 1989b). The first objective of this study was to investigate the effects of available water and nitrogen on the yield and grain protein concentration of stubbled-in winter wheat. Such studies have been carried out for winter wheat in other areas and for spring wheat on the prairies, however information for winter wheat in western Canada is lacking. Also, the recent introduction of a superior winterhardy semidwarf ('Norwin') allowed the investigation of N-response for both a tall ('Norstar') and a semidwarf cultivar. Fischer (1981) reported N-response for semidwarfs to be greater than tall types, however, Pearman et al. (1978) found no significant difference and Power and Alessi (1980) reported a higher N requirement for tall types.

The second objective of this study was to observe the influence of fertilizer N, water regime and genotype on crop growth, yield components and water use. Nitrogen fertilization is known to increase crop water use (Fischer and Kohn 1966; Campbell et al. 1977a) and WUE (Kallsen et al. 1984). Kernels m^{-2} usually increases with fertilizer N (Campbell et all 1977b; Ellen and Spietz 1980; Shanahan et al. 1984) while kernel weight often is unchanged (Ellen and Spietz 1980) or decreased (Frederick and Marshall 1985; Fowler et al. 1989a). The semidwarf character may also increase yield potential through the production of more kernels m^2 (Pearman et al. 1978) and a higher harvest index (Lupton et al. 1974). Information regarding the effects of fertilizer-N on growth, water use and yield formation of different winter wheat cultivars grown under different environmental conditions is important for developing N-management strategies for the semiarid and dry-subhumid areas of western Canada.

MATERIALS AND METHODS

General

Seven field trials were conducted in central Saskatchewan from 1984 to 1986 (Table 1). The experimental design for each trial was a split split plot with cultivars as main plots, water regimes as subplots, and N fertilizer rates as the sub-subplots. Two winter wheat cultivars, 'Norwin' and 'Norstar', were included in each trial. Norwin is a short statured semidwarf and Norstar is a tall cultivar. Norwin is not as winter hardy as Norstar and was winterkilled in three trials in this study (Table 1). These trials were analyzed using a split plot design with water regimes as the main plots and N fertilizer rates as the subplots. Water treatments consisted of irrigation to approximately 130% of the long term average (checked biweekly) beginning on May 15. Water was applied in amounts of 10 to 50 mm per irrigation using trickle or flood irrigation techniques. Total growing season precipitation and irrigation for each trial is shown in Table 1. Fertilizer N treatments consisted of four N rates (0, 33, 67 and 101 kg N ha^{-1}) applied as ammonium nitrate (34-0-0) topdressed in late April. Treatments were replicated three or four times except at Saskatoon in 1984 where only two replications were used.

Weather stations equipped with microloggers (Model CR-21; Campbell Scientific, Logan, Utah) were located at six of seven locations. Weather data for Saskatoon in 1986 was obtained from a nearby Environment Canada meteorological station. Daily values for minimum and maximum air temperatures and rainfall were recorded.

All trials were no-till seeded into standing barley (Hordeum vulgare L.) or rapeseed (Brassica campestris L.) stubble in late August or early September at a rate of 75 kg ha^{-1} and a row spacing of 20 cm. Plot size varied among locations, ranging from 8 to 15 m^2. Phosphate fertilizer (11-51-0) was applied with the seed at a rate of 13 kg P ha^{-1}. One neutron access tube was located in the centre of each plot. Soil water to 1.3 m was measured in early May (soon after resumption of growth), at stem elongation, anthesis and at harvest using a neutron probe (Model 3330; Troxler laboratories, Triangle Park, N.C.). Surface soil water (0 to 10 cm) was determined gravimetrically, then multiplied by bulk density value to convert to volumetric basis. Extractable soil water in the root zone and in the entire 1.3 m soil profile was determined at stem elongation and at anthesis. The methods used to determine both rooting depth and extractable soil water have been described in an earlier publication (Entz and Fowler 1988). Evapotranspiration (ET) expressed as precipitation (including irrigation) plus soil water use, was calculated for two time periods: May 1 to anthesis and May 1 to harvest. In the early spring of each year, mid-row soil samples to 61 cm were collected at each trial site to determine NO_3-N concentration (Table 1). Total available N was calculated as indigenous soil N plus fertilizer N.

Total aerial dry matter accumulation (dry matter) was determined at anthesis and maturity by harvesting two 1-m sections of row within each plot. Samples were dried for approximately 72 hours at 30°C before dry weights were determined. Spikes m^{-2} were estimated by counting a 1-m section of row within each plot at harvest. Plot area harvested for grain yield determination ranged from 6 to 12 m^2 depending on location. Grain samples were dried (30°C) to 8% water before yields were measured. Harvest index (HI) was calculated as the ratio of grain yield and dry matter at harvest. Grain protein concentration was determined by the Udy (1971) dye method and was expressed on an 8% water basis. Grain protein yield was calculated as grain yield times protein concentration. A subsample of 250 kernels from each plot was used to determine kernel weight (KWT) (mg kernel^{-1}). Kernel number (KNO) (kernels m^{-2}) was calculated by dividing grain yield m^{-2} by KWT. Water use efficiency (WUE) of grain yield was determined by dividing grain yield (kg ha^{-1}) by growing season ET (mm). Water use efficiency for dry matter production was calculated at anthesis and harvest. Data collected on each sampling date was subjected to analysis of variance. For or analysis of combined sites, heterogeneity of error variances were tested using the maximum F-test (Rohlf and Sokal 1969).

Nitrogen response

The inverse polynomial equation outlined by France and Thornley (1984), and implemented by Fowler et al. (1989a), was used to describe yield of grain and protein as a function of total available N. The function is as follows:

$$Y = \frac{\underline{u}N}{N + \underline{u}/\underline{e}} (1-N/\underline{s})$$

where $\underline{u}$ represents an upper limit to yield in the absence of yield depression, $\underline{e}$ represents the initial slope at low N levels, and $\underline{s}$ allows for the depression of yield at high N levels. That is, $\underline{s}$ is a measure of sensititity to excess levels of N (larger $\underline{s}$ indicates less sensitivity).

Non-linear regression procedures outlined by the SAS Institute (1985) were used to provide least-square estimates of the regression coefficients $\underline{u}$, $\underline{e}$ and $\underline{s}$. All three coefficients were successfully estimated for 14 or 22 grain yield N-responses and for 9 of 22 grain protein yield N-responses. All response were fit a second time using the average $\underline{s}$ values (518 for grain yield and 871 for grain protein yield).

The Gompertz equation, as implemented by Fowler et al. (1989b), was used to describe the relationship between grain protein concentration and total available N. The function is as follows:

$$P = \underline{M} + \underline{A}\exp\,[-\underline{B}\exp(-\underline{K}\underline{N})] \qquad [2]$$

where $\underline{P}$ = predicted protein concentration (14% water basis).

$\underline{M}$ = minimum protein concentration (set at 8.2% as per Fowler et al. 1989b).

$\underline{M} + \underline{A}$ = asymptotic protein concentration achieved at high N levels (a measure of protein concentration expected when N is not limiting).

$\underline{B}$ = determines N level at which protein concentration reaches $\underline{M} = 0.5\underline{A}$ (is a reflection of the total N required to produce a significant increase in grain protein concentration above $\underline{M}$.).

$\underline{K}$ = coefficient that determines the rate of P increase to $\underline{M} = \underline{A}$.

$\underline{N}$ = total available N (kg ha^{-1}).

The coefficient K was held constant at 0.02302 (Fowler et al. 1989b). Non-linear regression procedures outlined by the SAS Institute (1985) were used to provide least-square estimates of the coefficients A and B.

RESULTS AND DISCUSSION

Grain and Grain Protein Yield

The inverse polynomial equation (Eq. [1]) provided a curvilinear yield-N fertilizer response surface that conformed well with the general grain and grain protein yield trends observed for cultivars and water regimes in the present study (Figures 1 and 2). Average reduction in sums of squares due to the model was greater than 99% ($p \leq 0.01$) in all instances for both grain yield and grain protein yield. The regression coefficients for the equations that best described grain and protein yield N-fertilizer response in each trial are given in Tables 2 and 3. At Saskatoon in 1985, a combination of high indigenous soil N (260 kg ha^{-1}) and a low response to total available N (Figure 1) prevented the program from converging on estimates of e. The initial slope (e) was therefore fixed at the average of all other e values (Table 2). One equation was used to describe the average $\bar{N}$ response when cultivar or water effects were not significant ($p \leq 0.05$).

Similar N fertilizer response patterns were observed for grain and grain protein yield (Figures 1 and 2). Significant ($p \leq 0.05$) N responses for both grain and protein yield were recorded at Clair in 1985 and 1986, and at Outlook in 1986 (Figures 1 and 2). In the remaining trials, high residual soil N levels (Table 1) limited crop response to additional N. In all Saskatoon trials and in the Outlook 1985 trial, high N rates resulted in slight (NS) yield depression, especially for dryland compared to irrigation treatments (Figure 1). Yield depressions at high N rates were much less dramatic for grain protein yield (Figure 2). Similar results were reported by Fowler et al. (1988b).

Significant ($p \leq 0.05$) cultivar effects for grain and protein yield were only observed in the Saskatoon 1985 trial. A cultivar x water interaction ($p \leq 0.05$) for grain yield and protein yield indicated different responses to water for Norwin and Norstar in this trial (Figures 1 and 2). The average WUE for the irrigation water (kg ha^{-1} yield mm^{-1} irrigation water) was 17.5 and 9.7 kg ha^{-1} mm^{-1} for grain yield and 2.38 and 1.25 kg ha^{-1} mm^{-1} for protein yield of Norwin and Norstar, respectively. Laing and Fischer (1977) have also reported that semidwarf wheat cultivars outperform tall types under high productivity conditions. The absence of a significant ($p \leq 0.05$) cultivar x N interaction in this study indicated that the grain and grain protein yield-N responses were similar for Norwin and Norstar. Similar N response for tall and semidwarf wheat cultivars was also reported by Pearman et al. (1978).

The effect of irrigation on grain yield was significant ($p \leq 0.05$) in five of seven trials (Figure 10. A water x N interaction ($p \leq 0.05$) was recorded for grain yield in the remaining two trials (Outlook, 1986; Clair, 1985). The effect of water on grain protein yield was similar to the effect of water on grain yield (Figure 2). The only exception was at Outlook in 1986 where no significant effect of water on protein yield was observed.

Data for Norstar in trials with significant grain yield responses to N were combined for further analysis. These trials (Clair, 1985, 1986; Outlook, 1986) all had low residual soil N (average 40 kg ha^{-1}) and, compared with the other four trials with an average of 149 kg residual N ha^{-1}, represented typical commercial field conditions. A maximum F-test indicated that the error variances for grain and grain protein yield of the combined trials were homogeneous. Yield increase due to water alone was negligible, increase due to N alone was 708 kg ha^{-1} (from 2192 to 2900 kg ha^{-1}) while the increase due to N and water together was greatest (2192 to 3330 kg ha^{-1}) (Figure 1) indicating that 38% of the yield variation in these trials was attributed to the N x water interaction ($p \leq 0.05$).

For these combined trials, grain yield per increment of N applied was 23.9, 8.3, and 3.5 kg ha^{-1} kg N^{-1} under irrigation and 14.8, 6.6, and -8.3 kg ha^{-1} kg N^{-1} under dryland for the 33, 67, and 101 kg N ha^{-1} rates of added N, respectively. These results emphasized the importance of water for response of stubbled-in winter wheat crops to fertilizer N. The efficiency of the first increment of N applied under irrigation in the present study was similar to the maximum N efficiency of 25 kg ha^{-1} kg N^{-1} suggested for wheat by Henry et al. (1987).

Grain Protein Concentration

The Gompertz equation (Eq. [2]) provided an excellent description of the relationship between protein concentration and total plant-available N (Figure 3). Average reduction in sum of squares due to the model was 98% ($p \leq 0.01$). The regression coefficients for the grain protein concentration-N response equations are given in Table 4. Additions of fertilizer N significantly ($p \leq 0.05$) increased grain protein concentration in all instances except at Saskatoon in 1984 and 1985 (Figure 3). Values of $\underline{B}$ in Eq. [2] reflect the amount of N required to produce a significant increase in grain protein concentration above 8.2%. In the three low residual N trials $\underline{B}$ values were positively correlated with dry matter yield at anthesis (DMa) ($r=0.97^{**}$; $n=6$) and root zone extractable water at stem elongation ($r=0.85^{*}$; $n=6$). These relationships indicate that factors favoring growth during the preanthesis period increased the amount of total available N required to produce an initial increase in grain protein concentration.

Additions of water generally decreased grain protein concentration (Figure 3). Similar observations have been reported for both spring and winter wheat (Fernandez and Laird 1959; Smika and Greb 1973; Bole and Dubetz 1986). Significant ($p \leq 0.05$) differences however, were only recorded at Outlook in 1985 and at Saskatoon in 1984. These two trials received among the highest levels of irrigation water (Table 1) and thus, the effect of water was greatest in these trials.

Values of A (asymptotic protein concentration) varied widely (Table 4) and were negatively correlated with precipitation (including irrigation) from May 1 to anthesis ($r=0.67^{**}$; $n=22$). Negative relationships between pre-anthesis water availability and grain protein concentration have been previously reported for spring and winter wheat (Dubetz and Bole 1973; Smika and Greb 1973; Entz and Fowler 1988). These observations emphasize that in order to maintain a minimum grain protein concentration of stubbled-in winter wheat in Saskatchewan, increased water availability must be accompanied by increased levels of plant-available N.

Significant ($p \leq 0.05$) cultivar differences for grain protein concentration occurred in two of four trials (Figure 3). The higher protein concentration of Norwin compared to Norstar at Outlook in 1986 could be attributed to the inverse relationship between grain yield and protein concentration (Terman et al., 1969). Significantly higher grain protein concentration for Norwin at Saskatoon in 1985 could not be explained on the basis of a lower grain yield. Higher grain protein concentration for Norwin compared with Norstar in this trial may have been due to other factors such as greater N uptake or greater translocation of N from the leaves to the developing kernels. Non-significant ($p \leq 0.05$) cultivar x water and cultivar x N interactions indicated that grain protein concentration of Norstar and Norwin responded similarly to fertilizer N and water additions in these trials.

Crop Growth and Water Use

Norwin significantly ($p \leq 0.05$) outyielded Norstar at Saskatoon in 1985. The basis for the yield advantage for Norwin in this trial appeared to be a greater KNO, HI and WUE. These observations are in agreement with results of another study in which these two cultivars were compared across different environments (Entz and Fowler, unpublished data). In that study, Norwin produced more kernels m^{-2}, had a more favorable dry matter distribution before and after anthesis and had a higher WUE and grain yield than Norstar, when produced under favorable moisture conditions.

Growth and water use characteristics for Norstar in the combined analysis of low N trials are given in Tables 5, 6, 7 and 8. Error variances for yield components, dry matter and water use measurements were found to be homogeneous ($p \leq 0.05$) in most instances. Differential response of WUE (grain yield only) to N, however, resulted in a significant location x N interaction (Table 8). In both years at Clair, WUE increased with N in a curvilinear fashion.

Growth and water use characteristics in these trials were affected more by N than by water. The only significant effect of water was a water x N interaction for KNO (Table 5). Response of KNO to N was greater in the irrigated compared to the dryland treatments.

The influence of fertilizer N on crop growth was greatest during the pre-anthesis period. Additions of N significantly increased spikes m^{-2}, KNO and DMa (Table 5). Similar response to added N by these variables have been reported by Campbell et al. (1977b), Shanahan et al. (1984) and Rickman et al. (1975), respectively. These results point out the strong effect of N on increasing the crop yield potential at anthesis. Increases in KNO with N (Table 5) were closely associated with increases in grain yield due to N (r ranged from 0.85** to 0.99**). This observation supports the conclusion of Ellen and Spietz (1980) and Shanahan et al. (1984) that N stimulated yield increases are due to increased kernel production.

The influence of fertilizer N on post-anthesis growth was less dramatic. Dry matter yield increased an average of approximately 4000 kg ha^{-1} from anthesis to harvest at all N rates considered (Table 6). Therefore, the advantage gained by fertilized crops did not increase after anthesis. HI was also unaffected by N (Table 5) suggesting that there was not an optimum N level for conversion of dry matter to grain yield. Increased N significantly decreased KWT (Table 5) indicating a greater competition for assimilates at higher N rates (Ellen and Spietz 1980). The absence of a significant yield decrease with fertilizer N applications suggested that the decrease in KWT with N was more than offset by the significant increase in KNO (Table 5). Similar observations have been made by Darwinkel (1978), Ellen and Spietz (1980) and Shanahan et al. (1984). Shanahan et al. (1984) suggested that high KNO due to N applications increased the post-anthesis sink for assimilates, thereby increasing the potential yield. Ellen and Spietz (1980) found that under favorable moisture conditions grain yield increased up to 19,000 kernels m^{-2}, however above this level yields declined. The threshold level for KNO in the prairie region would be expected to be lower. In the present study, the threshold level under dryland was approximately 8900 kernels m^{-2} (Table 5). The optimum level of KNO under dryland corresponded with a total available N level of approximately 110 kg ha^{-1}. Under partial irrigation (130% of normal rainfall) this threshold KNO was approximately 10,000 kernels m^{-2} and corresponded with a total available N level of approximately 140 kg ha^{-1}.

Nitrogen additions did not significantly increase crop water use or evapotranspiration (ET) in the present study (Table 7). However, similar to previous reports (Campbell et al. 1977; de Jong and Cameron 1980; Kallsen et al. 1984), N additions significantly increased the WUE of the grain yield (Table 8). Nitrogen additions also increased the WUE of DMa and DMm (Table 8). Because N did not increase ET, increased WUE owing to greater water use (de Jong and Cameron 1980) was ruled out as a possibility. Fischer and Turner (1978) suggested that WUE in crops grown in water-limiting environments can be increased only by increasing transpiration as a fraction of total ET, mainly by reducing direct soil-evaporation. In the present study, greater aerial dry matter for N-fertilized crops (Table 6) may have reduced direct soil-evaporation, thereby increasing the proportion of water which actually passed through the plant. Such a hypothesis is supported by Kallsen et al. (1984) who observed that grain yield mm^{-1} ET was significantly increased by added N while grain yield mm^{-1} water actually transpired through the plant was unaffected. Therefore, in order for N to increase WUE, N must have increased the proportion of ET that passed through the plants.

In conclusion, the observations made in this study have once again demonstrated that N fertilization has an important influence on winter wheat yield and quality. Water also had a large effect on yield emphasizing the importance of prevailing environmental conditions in determining the N-response of stubbled-in winter wheat in Saskatchewan. The main effects of N on crop growth parameters in these trials were to increase pre-anthesis assimilation, KNO, and WUE. All of these factors have been previously identified as important contributors to yield of wheat produced in water-limiting environments (Fischer 1981; French and Schultz 1984; Shanahan et al. 1984). Where residual soil NO_3-N levels are at "typical" Saskatchewan stubble field levels (less than 40 kg N ha^{-1}), grain protein concentration cannot be expected to exceed the minimum quality standards for hard red winter wheat (approximately 11%) without N-fertilization. In the present study, as pre-anthesis growing conditions improved, higher levels of available N were required to achieve an initial increase above a minimum 8.2% protein concentration. Consequently, N-management strategies to increase pre-anthesis assimilation and kernel production must also pay special attention to potentially low grain protein concentration resulting from the "dilution" effect of higher grain yields.

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Table 1. Test location, soil characteristics and growing season precipitation (GSP) for winter wheat genotype, water and N fertilizer rate trials, 1984 to 1986.

		Soil		GSP (mm)††	
Trial	Year	Soil type†	NO_3-N in early spring (kg ha^{-1})	Dryland	Irrigation
1. Saskatoon§	1983/84	Sutherland clay	90	105	255
2. Saskatoon	1984/85	Bradwell clay loam	260	146	271
3. Saskatoon	1985/86	Bradwell clay loam	140	170	211
4. Clair§	1984/85	Yorkton loam	53	214	295
5. Clair	1985/86	Yorkton loam	21	220	260
6. Outlook§	1984/85	Asquith fine sandy loam	106	94	216
7. Outlook	1985/86	Asquith fine sandy loam	46	218	272

†Canada Soil Survey Committee, Subcommittee on Soil Classification. 1978. The Canadian system of soil classification. Can. Dept. Agric., Supply and Services Canada, Ottawa, Ont. Publ. 1646.

††Growing season precipitation - May 1 to maturity.

§Indicates trials in which Norwin was winterkilled.

Table 2. Estimated regression coefficients (eq.[1]) for grain yield of winter wheat in genotype, water and N fertilizer rate trials.

Trial	Treatment†	u	e	s
Saskatoon 1983/84	IRR	7905	88.7	518
	DRY	2353	125.7	518
Saskatoon 1984/85	IRR Norstar	9551	79.9	901
	DRY Norstar	5216	79.9	1316
	IRR Norwin	8950	79.9	2367
	DRY Norwin	4815	79.9	2367
Saskatoon 1985/86	IRR, Norstar, Norwin	8585	29.3	518
	DRY, Norstar, Norwin	7537	22.5	518
Clair 1984/85	IRR	7946	63.6	518
	DRY	5030	96.9	518
Clair 1985/86	IRR, Norstar, Norwin	6510	88.8	518
	DRY, Norstar, Norwin	4241	115.5	518
Outlook 1984/85	IRR	5732	65.6	518
	DRY	3984	32.8	518
Outlook 1985/86	IRR, Norstar, Norwin	7190	103.5	518
	DRY, Norstar, Norwin	5581	95.3	518

†IRR-irrigation treatment; DRY-dryland treatment.

Table 3. Estimated regression coefficients (Eq. [1]) for grain protein yield of winter wheat in genotype, water and N fertilizer rate trials.

Trial	Treatment†	u	e	s
Saskatoon 1983/84	IRR	763	10.9	871
	DRY	238	80.1	871
Saskatoon 1984/85	IRR Norstar	1394	8.8	871
	IRR Norwin	1349	4.4	871
	DRY Norstar	6882	3.4	871
	DRY Norwin	1793	4.5	871
Saskatoon 1985/86	IRR, Norstar, Norwin	551	3.8	871
	DRY, Norstar, Norwin	569	2.7	871
Clair 1984/85	IRR	742	6.4	871
	DRY	502	10.3	871
Clair 1985/86	IRR, Norstar, Norwin	908	6.9	871
	DRY, Norstar, Norwin	531	9.6	871
Outlook 1984/85	IRR	522	13.3	871
	DRY	387	6.2	871
Outlook 1985/86	ALL	679	7.6	871

†IRR-irrigation treatment; DRY-dryland treatment; ALL-includes all treatments.

Table 4. Estimated regression coefficients (Eq. [2]) for grain protein concentration of winter wheat in genotype, water and N fertilizer rate trials.

Trial	Treatment†	A	B
Saskatoon 1983/84	IRR	4.3	2.4
	DRY	56.9	0.8
Saskatoon 1984/85	Norstar, IRR, DRY	4.3	20.6
	Norwin, IRR, DRY	20.6	9.4
Saskatoon 1985/86	ALL	4.3	8.2
Clair 1984/85	ALL	3.4	1.5
Clair 1985/86	ALL	4.4	2.2
Outlook 1984/85	IRR	5.4	1.0
	DRY	6.6	1.2
Outlook 1985/86	Norstar, IRR, DRY	2.6	7.9
	Norwin, IRR, DRY	4.2	4.1

†IRR-irrigation treatment; DRY-dryland treatment; ALL-includes all treatments.

Table 5. The influence of N rate on yield components of no-till Norstar winter wheat. Mean from three trials (Clair, 1985 and 1986; Outlook, 1986).

N rate ($kg\ ha^{-1}$)	spikes m^{-2}	kernels m^{-2}		kernel weight (mg)
		†Irrigation	Dryland	
0	329	6270	6480	32.1
33	414	8860	8170	31.1
67	403	9460	8920	31.4
101	430	10090	8130	30.8
	*	**	**	*

*, **Significant at the 0.05 and 0.01 probability levels, respectively.

†Indicates a significant ($p \leq 0.05$) water regime X N interaction.

Table 6. The influence of N rate on dry matter at anthesis (DMa), dry matter at maturity (DMm) and harvest index (HI) of no-till Norstar winter wheat. Mean from three trials. (Clair, 1985 and 1986; Outlook, 1986).

N rate ($kg\ ha^{-1}$)	DMa ($kg\ ha^{-1}$)	DMm ($kg\ ha^{-1}$)	HI
0	2664	6211	0.34
33	4304	7850	0.35
67	4745	8294	0.37
101	4665	8694	0.33
	**	**	NS

**Significant at the 0.01 probability levels.

Table 7. The influence of N rate on evapotranspiration (ET) of no-till Norstar winter wheat. Means from three trials (Clair, 1985 and 1986; Outlook, 1986).

N rate (kg ha^{-1})	Pre-anthesis ET (mm)	Post-anthesis ET (mm)	Growing season ET (mm)
0	142	143	286
33	148	145	294
67	155	141	297
101	150	147	297
	NS	NS	NS

Table 8. The influence of N rate on water use efficiency (WUE) of no-till Norstar winter wheat. Means from three trials (Clair, 1985 and 1986; Outlook, 1986).

N rate (kg ha^{-1})	WUE of DMa (kg ha^{-1} mm^{-1} ET)	WUE of DMm (kg ha^{-1} mm^{-1} ET)	†WUE of grain yield (kg ha^{-1} mm^{-1} ET) Clair 1985	Clair 1986	Outlook 1986
0	21.3	22.5	6.7	7.1	7.9
33	32.1	27.0	7.8	10.0	10.4
67	33.8	28.9	8.3	12.5	10.5
101	34.2	30.0	8.6	12.5	9.6
	**	**	*	**	**

*, **Significant at the 0.05 and 0.01 probability levels, respectively.

†Indicates a significant ($p \leq 0.05$) location X N interaction.

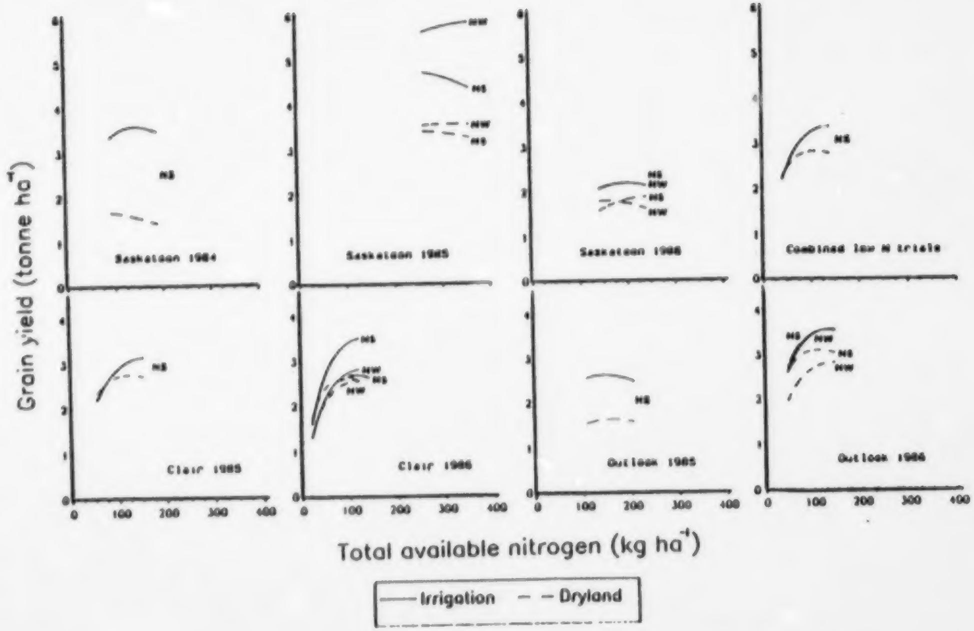

Figure 1 Grain yield response of irrigated and dryland Norstar (NS) and Norwin (NW) winter wheat to total available nitrogen.

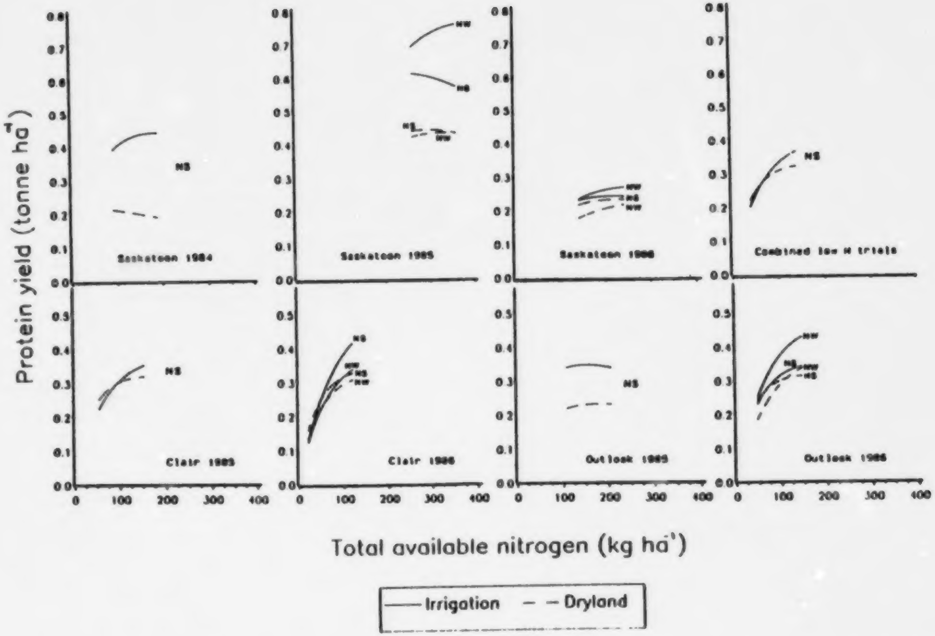

Figure 2 Grain protein yield response of irrigated and dryland Norstar (NS) and Norwin (NW) winter wheat to total available nitrogen.

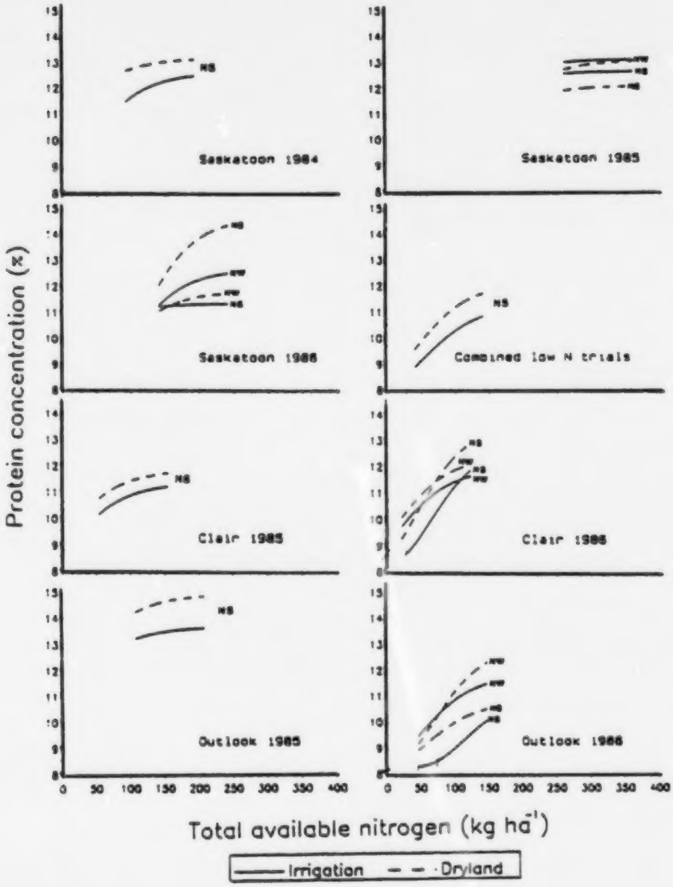

Figure 3 Grain protein concentration response of irrigated and dryland Norstar (NS) and Norwin (NW) winter wheat to total available nitrogen.

NUTRIENT STATUS OF MANITOBA SOILS - FALL 1988

J. Ewanek and K.S. McGill
Manitoba Agriculture

Soil test sample submission statistics for the years 1979-80 to 1988-89 are summarized in Table 1. The largest sample volumes were recorded for the years 1980-81 to 1983-84, during this period the numbers exceeded 12,000 samples per year. The record sample year to date was 1981-82 with 15,430 fields. Since 1984-85 and until this soil testing year there was a marked decline in the number of fields. Because of the interest in nutrient levels after the drought, this year's sample numbers have increased to over 10,000. Table 1 shows that the area which was annually soil sampled is reflective of the fields sampled annually. This fall over 378,000 hectares of farmland were sampled. During this period from 1979-80 the average number of fields submitted per client has ranged from 3.4 to 4.1; with this year's average being 4.0.

The percent of the total samples submitted by industry on behalf of farm clients has been relatively constant at 60-68 percent. This fall the percentage increased to 75 percent.

Table 2 shows that with some variations the percent of farm samples submitted to the laboratory from each Manitoba Agriculture Region has remained relatively constant over the past ten year period with an average of 30% from each of the Central and Southwest regions and 16, 10 and 8% from the Northwest, Interlake and Eastern regions respectively.

Soil Nitrate-Nitrogen Levels

This fall's provincial average nitrogen levels of 83 kg/ha on stubble land (Table 3) are the highest ever recorded by the Provincial Laboratory. The levels are 63 percent above the previous nine year average of 51 kg/ha. The high levels are attributed mainly to the high rates of nitrogen which were applied for the 1988 crop and were not used because of the severe drought.

Regionally this fall's nitrogen levels on stubble fields have been strongly influenced by the occurrence of the drought. The regions which were hardest hit by the drought were Central, Southwestern and the Southwestern corner of the Eastern region. The nitrogen levels for these three regions were 98, 60 and 45 percent above the previous nine year average respectively. In the other two regions, Interlake and Northwest, the nitrogen levels were slightly above and at the nine year average.

This fall's nitrate nitrogen levels on fallow fields (Table 4) is above the nine year average in the Southwest, Northwest and Eastern regions; 87, 94 and 108 kg/ha respectively. In the Central region the nitrogen is 30 kg/ha higher than average and in the Interlake 18 kg/ha lower than average.

Phosphorus Levels

Extractable phosphorus levels (Table 5) have remained relatively constant both province wide at an average of 25 kg/ha and within each region at an average of 25 kg/ha for both the Interlake and Eastern regions and 28, 22 and 23 kg/ha for the Central, Southwestern and Northwest regions respectively.

Potassium Levels

Province wide the potassium levels (Table 6) are above the nine year average at 707 kg/ha and 799, 692, 495, 716 and 645 for the Central, Southwest, Northwest, Interlake and Eastern regions respectively.

Sulphur Levels

The majority and the fields in the province are in the very high to very high + category for available sulphur (Table 7); 77 percent of stubble fields and 78 percent of the fallow fields are in this category. Seventeen percent of stubble fields and 22 percent of fallow fields are in the very low to medium levels; at these levels high sulphur use crops such as canola and alfalfa would receive a recommendation for sulphur fertilizer.

Table 1. Farm Soil Sample Submissions to the Manitoba Provincial Soil Testing Laboratory (1979-80 to 1988-89)*

Year	Number of Fields	Number of Clients	Fields per Client	% Submitted By Industry Sources	Area Sampled (,000 ha.)
1979-80	8325	2270	3.7	56	240
1980-81	12700	3260	3.9	61	380
1981-82	15430	3830	4.0	68	480
1982-83	12515	3160	4.0	63	400
1983-84	12370	3040	4.1	62	395
1984-85	9750	2455	4.0	61	325
1985-86	5930	1599	3.7	60	185
1986-87	5769	1692	3.4	66	183
1987-88	7634	2172	3.5	67	239
1988-89	10467	2647	4.0	75	378

* Based on crop year July 1 to June 30 of the following year. For 1988-89 data is for the period July 1 to Dec. 31, 1988.

Table 2. Percent of Farm Samples Submitted from the Five Manitoba Agriculture Regions (1979-80 to 1988-89)*

Year	Percent of Farm Samples from the Following Regions: Central	Southwest	Northwest	Interlake	Eastern
1779-80	25	33	21	8	8
1980-81	30	29	18	7	8
1981-82	31	33	18	8	7
1982-83	30	27	16	8	8
1983-84	34	28	14	11	10
1984-85	32	33	12	12	9
1985-86	31	30	17	10	9
1986-87	27	27	17	14	9
1987-88	27	30	17	13	8
1988-89	34	30	13	14	6

* Based on crop year July 1 to June 30 of the following year. For 1988-89 data is for the period July 1 to Dec. 31, 1988.

Table 3. Average Nitrate-Nitrogen Levels in Stubble Fields Soils in Manitoba and in Individual Manitoba Agriculture Regions of Manitoba (1979-80 to 1988-89)*

	Average Nitrate-Nitrogen Content to 60 cm (kg/ha)					
	Province	Region				
Year	Wide	Central	Southwest	Northwest	Interlake	Eastern
1979-80	54	46	55	49	80	53
1980-81	59	62	52	54	79	67
1981-82	58	61	56	53	69	63
1982-83	46	49	39	44	55	52
1983-84	58	67	51	50	66	58
1984-85	63	61	69	55	57	52
1985-86	38	42	33	29	52	55
1986-87	38	45	32	31	52	41
1987-88	42	47	37	39	45	51
1988-89	83	105	75	55	64	80

* Based on crop year July 1 to June 30 of the following year. For 1988-89 data is for the period July 1 to Dec. 31, 1988.

Table 4. Average Nitrate-Nitrogen Levels in Fallow Field Soils in Manitoba and in Individual Manitoba Agriculture Regions of Manitoba (1979-80 to 1988-89)*

	Average Nitrate-Nitrogen Content to 60 cm (kg/ha)					
	Province	Region				
Year	Wide	Central	Southwest	Northwest	Interlake	Eastern
1979-80	97	132	86	86	120	98
1980-81	108	119	83	112	122	137
1981-82	105	106	101	116	90	103
1982-83	96	112	89	92	92	96
1983-84	119	144	105	109	115	162
1984-85	104	115	101	98	106	106
1985-86	70	78	43	58	102	92
1986-87	110	98	89	97	133	88
1987-88	83	79	84	80	86	87
1988-89	106	149	92	105	89	108

* Based on crop year July 1 to June 30 of the following year. For 1988-89 data is for the period July 1 to Dec. 31, 1988.

Table 5. Average NaHCO3 Extractable Phosphorus Levels in Field Soils in Manitoba and in Individual Manitoba Agriculture Regions of Manitoba (1979-80 to 1988-89)*

Year	Average Phosphorus Content to 15 cm (kg/ha)					
	Province Wide	Region				
		Central	Southwest	Northwest	Interlake	Eastern
1979-80	19	21	17	18	19	21
1980-81	22	26	18	19	24	26
1981-82	21	25	19	19	23	25
1982-83	21	24	17	20	22	25
1983-84	21	23	18	20	21	22
1984-85	22	25	22	20	21	22
1985-86	20	22	18	18	21	23
1986-87	20	21	17	20	22	23
1987-88	20	21	18	19	21	25
1988-89	25	28	22	23	25	25

* Based on crop year July 1 to June 30 of the following year. For 1988-89 data is for the period July 1 to Dec. 31, 1988.

Table 6. Average NH4AC Extractable Potassium Levels in Field Soils in Manitoba and in Individual Manitoba Agriculture Regions of Manitoba (1979-80 to 1988-89)*

Year	Average Potassium Content to 15 cm (kg/ha)					
	Province Wide	Region				
		Central	Southwest	Northwest	Interlake	Eastern
1979-80	555	565	590	435	630	569
1980-81	630	690	650	435	725	710
1981-82	610	656	615	545	735	720
1982-83	630	690	620	505	725	695
1983-84	605	620	610	465	610	705
1984-85	610	635	605	445	640	720
1985-86	620	665	635	455	615	675
1986-87	655	750	635	515	690	615
1987-88	600	650	590	475	640	615
1988-89	707	799	692	495	716	645

* Based on crop year July 1 to June 30 of the following year. For 1988-89 data is for the period July 1 to Dec. 31, 1988.

Table 7. Percent of Fields Tested by the Manitoba Soil Testing Laboratory in Various Sulphur Availability Categories (Province Wide)

Year	% of Fields in Each Sulphur Availability Category*			
	Very Low and Low	Medium	High	Very High and Very High +
STUBBLE FIELDS				
1979-80	7	7	6	80
1980-81	4	7	8	81
1981-82	8	10	8	74
1982-83	4	9	9	78
1983-84	2	4	5	89
1984-85	2	6	7	85
1985-86	2	8	11	79
1986-87	4	10	9	77
1987-88	12	10	7	71
1988-89**	10	7	6	77
FALLOW FIELDS				
1979-80	5	5	6	84
1980-81	3	7	10	80
1981-82	6	10	11	73
1982-83	4	9	11	76
1983-84	2	4	6	88
1984-85	2	7	8	83
1985-86	0	7	11	82
1986-87	1	11	9	75
1987-88	13	16	10	61
1988-89**	13	9	9	78

* Very Low and Low - all crops receive a fertilizer sulphur recommendation.

Medium - Canola, mustard, annual and perennial legumes and other "special" and horticultural crops receive a fertilizer recommendation.

** Based on crop year July 1 to June 30 of the following year. for 1988-89 data is for the period July 1 to Dec. 31, 1988.

ACID-BASED NITROGEN AND PHOSPHORUS FERTILIZERS

G.J. Racz
Department of Soil Science, University of Manitoba

Acid-based nitrogen-phosphorus fertilizers are usually a combination of urea and phosphoric acid with or without sulfuric acid. The blends have a low pH (near a pH = 1.0 in instances), but pH depends on the proportion of compounds used in the blend.

Interest in acidified fertilizers has been generated because they possess a number of chemical characteristics which may be beneficial in enhancing fertilizer efficacy. The claims generally made are:

(1) a greater solubility of phosphorus in fertilizer bands with acidified fertilizers than with products such as monoammonium phosphate due to the lower pH of the acidified product.

(2) enhanced efficacy of nitrogen fertilizer use by plants from fertilizers such as acidified urea than from urea due to the lower pH of the former. The lower pH of the acidified product may decrease ammonia volatilization.

(3) less damage to seeds and seedlings with fertilizers such as acidified urea than with urea. The acidified fertilizer may produce an acid environment in the zone of application which may reduce ammonia concentrations.

(4) a solubilization of soil minor elements within the zone of fertilizer placement with acidified fertilizers resulting in increased minor element availability to plants.

This paper examines each of the above claims and discusses whether or not acidification of fertilizers results in a greater efficacy of fertilizer use by plants.

(1) Phosphorus Solubility in Fertilizer Bands

Claims are being made that acid fertilizers acidify the zone of fertilizer application, particularly in calcareous soils, which results in increased phosphorus availability. Studies by several researchers have been conducted to address this issue. The results of these studies are summarized below.

Westfall and Hanson (D.G. Westfall and R.L. Hanson, 1985, J. of Fert. Issues 2:42-46) studied the effects of acidified and nonacidified fertilizers on the pH and solubility of phosphorus in the zone of fertilizer placement over time using an acidic and a calcareous Colorado soil. The fertilizer treatments were: (1) no fertilizer, (2) APP (10-34-0) alone, (3) APP and NH_4OH (dual N-P band), and (4) AUP (sulfuric acid, phosphoric acid and urea (14-14-0-4.4)).

The application of AUP to the acidic Ascalon soil resulted in a dramatic decrease in pH one day after application (Table 1). However, the effect of the AUP on pH of the fertilizer reaction zone was very temporary and after 10 days the pH in the AUP band was essentially identical to the other fertilizer treatments. Application of fertilizer, regardless of type, did not change the pH of the fertilizer zone for the calcareous Weld soil. This was due to the buffering effect of the lime in the soil.

The $NaHCO_3$ - extractable phosphorus concentrations (Table 2) in the AUP fertilizer bands in the acidic Ascalon soil was about equal to that of the NH_4OH plus APP treatment during 1 to 25 days after application. After 25 days of incubation, phosphorus concentrations in the AUP bands were less than for other treatments. In the calcareous Weld soil, extractable phosphorus in the fertilizer bands one day after fertilizer application decreased in the order, AUP>NH_4OH + APP> APP alone. The extractable phosphorus level in the AUP band dropped very rapidly after one day of incubation, and after 10 days of incubation extractable phosphorus levels in the AUP bands ranged from 39 to 52% lower than the NH_4OH + APP band and from 30 to 36% lower than the APP alone treatment.

It is interesting to note that the dual N-P band resulted in higher $NaHCO_3$ - extractable phosphorus concentrations than the APP alone treatment for both soils and higher phosphorus concentrations than the AUP in the calcareous soil after 10 days of incubation. Phosphorus concentrations in the acidic soil were similar for the dual N-P band and AUP during the first 25 days of incubation. After 25 days of incubation, extractable phosphorus in the acidic soil was greater with the dual N-P band than with AUP.

Studies similar to those reported above were conducted by Beever and Racz (unpublished data, Dept. of Soil Science, Univ. of Manitoba) using an acidic (pH=5.6), a neutral (pH=7.2), and a calcareous (pH=8.5) soil. The effects of various nitrogen fertilizers on pH and phosphorus solubility in dual N-P fertilizer bands were studied using monoammonium phosphate (MAP) as the phosphorus fertilizer. Applications in the fertilizer bands were equivalent to 80 kg N/ha and 20 kg P/ha.

All nitrogen fertilizers used were conventional fertilizers except for the acidified urea which consisted of urea plus phosphoric acid. The fertilizers were added in dual bands and incubated for 4 weeks at 20 C. Soil pH values in the dual N-P bands in the acidic Stockton LS soil were higher than that of the soil per se (Table 3). pH in the dual N-P bands increased in the order: ammonium sulfate $\simeq$ ammonium nitrate < ammonium hydroxide < acidified urea ≃ urea. pH values of 8.4 or greater were noted when acidified urea or urea was added to the fertilizer band. Soil pH in the fertilizer bands in the neutral Stockton FSL soil was about 7.0 with ammonium sulfate and ammonium nitrate and about 8.4 with urea and acidified urea. Soil pH in the fertilizer bands of the calcareous Almasippi soil did not vary greatly with treatment and was about 8.6 to 8.9.

Solubility of phosphorus in the various fertilizer reaction zones was expressed for each soil and treatment as total mg of phosphorus which was entracted by water from the entire fertilizer reaction zone (Table 4). The solubility of phosphorus in the MAP fertilizer band in the acidic Stockton soil increased when urea, ammonium hydroxide or acidified urea were added; ammomium sulphate and ammonium nitrate had little or no effect on phosphorus solubility in the dual N-P bands. Solubility of phosphorus in the MAP fertilizer bands in the neutral Stockton soil was increased by all nitrogen fertilizers except ammonium nitrate. Solubility of phosphorus in the MAP band in the calcareous Almasippi soil increased with the application of urea, ammonium hydroxide or acidified urea and decreased when ammonium sulfate or ammonium nitrate was added. Urea alone generally increased phosphorus solubility to a greater extent than acidified urea in all instances.

Solubility of phosphorus in the dual N-P bands was usually higher with the alkaline nitrogen fertilizers (urea) than with the more acidic nitrogen fertilizers (e.g., ammonium sulfate). Other studies conducted by Racz and others (unpublished data, Dept. of Soil Science, University of Manitoba) showed that calcium concentrations in dual N-P bands with alkaline nitrogen fertilizers was less than with acidic nitrogen fertilizers. The high pH in dual N-P bands with the alkaline nitrogen fertilizers would decrease the solubility of carbonates containing calcium and/or magnesium. The higher concentration of calcium and/or magnesium in the dual N-P bands with the acidic salts (e.g., ammonium sulfate) was most likely responsible for the lower phosphorus solubility with acidic than with alkaline nitrogen fertilizers.

(2) Yield and Phosphorus Utilization by Plants

Plant growth studies are required to assess fully the availability of phosphorus to plants from various fertilizer treatments. Bole (J.B. Bole, 1986, Can. J. Soil Sci. 66:189-193) compared a solution of acid-urea-phosphate fertilizer with a mixture consisting of conventional granular urea and monoammonium phosphate (MAP) using ^{32}P labelled phosphorus. The acid-urea-phosphate was a mixture of phosphoric acid, sulfuric acid, urea and potassium chloride with an analysis of 16-8-3-4. Yield of dry matter of soft white wheat (Table 5) for the two sources of phosphorus were similar. Percent utilization of phosphorus was greater for the banded-P than for treatments with P thoroughly mixed with the soil, particularly for the urea and MAP source of phosphorus (Table 6). Percent utilization of the added phosphorus was similar for both sources of phosphorus when mixed with the soil. However, percent utilization of added phosporus for MAP-urea was greater than for acid-urea-phosphate when the fertilizers were banded into the soil.

Varvel and others (G.E. Varvel, H.L. Meredith and R.K. Severson, 1986, Agron. J. 78:775-779) evaluated acid-based fertilizers on highly calcareous soils in the Red River Valley area of Minnesota and North Dakota. Urea phosphate (UP), an experimental acidified material, was compared to diammonium phosphate (DAP) at three locations over a three-year period. The fertilizers were applied in the seed-row (Table 7). Grain yields were similar for both sources of phosphorus. Phosphorus content of total above ground plant matter at maturity was slightly greater with DAP than with urea phosphate.

Racz and others (unpublished data, Dept.of Soil Science, University of Manitoba) have recently shown that phosphorus uptake by plants from dual urea-monoammonium phosphate bands was reduced during the seedling stage if planting occurred immediately after fertilization. The delay in phosphorus uptake was attributed to high concentrations of ammonia in the urea-dual N-P bands which restricted root growth into the bands. Studies were conducted, using Canola as a test crop on a calcareous Almasippi soil, to evaluate methods of reducing ammonia concentrations in urea N-P dual bands and thus enhance phosphorus uptake by plants during the seedling stage. Treatments included:

(1) urea banded, MAP near the seed;
(2) Urea + MAP dual banded;
(3) ammonium sulphate + MAP dual banded;
(4) urea and phosphoric acid dual banded;
(5) urea + MAP dual banded but with seeding delayed 10 days after fertilization.

Days to initiation of fertilizer phosphorus uptake was greater for the non-incubated urea + MAP dual bands than for the incubated urea + MAP and the ammonium sulfate + MAP dual bands (Table 8). The use of phosphoric acid instead of monoammonium phosphate did not reduce the delay in fertilizer phosphorus uptake from the urea dual bands. Incubation of the urea + MAP dual band, however, did enhance fertilizer phosphorus uptake during the seedling stage. Days to initiation of fertilizer phosphorus uptake when the urea and MAP was incubated was about equal to that with ammonium sulfate.

Uptake of fertilizer phosphorus at the flowering stage was also measured (Table 8) and varied from 44 to 52%. Fertilizer phosphorus uptake at this stage of growth was slightly less for the urea and phosphoric acid treatment than for other dual bands.

Yield with the various non-incubated dual bands were similar. Yield was highest when the phosphorus was placed near the seed and intermediate with the incubated urea and MAP dual band.

(3) Volatilization of Nitrogen as Ammonia

Losses of nitrogen from fertilizers, such as urea, occurs via ammonia volatilization when the fertilizer is not worked into the soil. Rate of loss and amount usually increase with increasing soil pH and pH of the fertilizer. Research has been conducted to determine the effects of acidifying fertilizers such as urea on amounts of nitrogen volatilized as ammonia. Bremner and Douglas (J.M. Bremner and L.A. Douglas, 1971. Soil Sci. Soc. Amer. Proc. 35:575-578) incubated five Iowa soils varying in pH from 6.8 to 7.8 with urea and urea-phosphate (urea and phosphoric acid). They reported that the phosphoric acid contained in the urea-phosphate reduced ammonia volatilization (Table 9). The percentage loss of nitrogen as ammonia after 14 days of incubation varied from 4.6 to 61% for urea (average of 21.2%) but was only 0.1 to 1.1% (average of 0.7%) for the urea phosphate.

In contrast to the findings noted above, Stumpe and others (J.M. Stumpe, P.L.G. Vlek, and W.L. Lindsay, 1984, Soil Sci. Soc. Amer. J. 48:921-927) found no differences in ammonia volatilized from urea and acid-urea-phosphate when applied to the surface of a calcareous soil (Table 10). They suggested that urea-phosphate mixtures should not be recommended as a means of reducing ammonia volatilization on highly calcareous soils.

The results of these studies generally indicate that losses of nitrogen as ammonia from acid-urea-phosphates are less than from urea when surface applied but only on neutral or acidic soils. Ammonia volatilization was equal and high for both urea and acid-urea-phosphate on calcareous soils. The lime in the calcareous soils quickly neutralizes the acidity from the acid-urea-phosphate and, hence, pH near the granule for urea and acid-urea-phosphate are about the same. It should also be noted that many other studies (not reported here) have shown initially no loss of ammonia from any form of nitrogen fertilizer when it is banded into the soil.

(4) Reduction in Toxicity to Seeds and Seedlings

Fertilizers, such as urea, reduce germination and emergence when added at high rates with the seed. Urea has been shown to reduce emergence much more than fertilizers, such as ammonium nitrate, when applied at equal rates with the seed. Ammonia toxicity from the urea is considered to be responsible for the reductions in emergence at high rates of application. Therefore, reductions in germination and emergence could be partly alleviated if the pH in the fertilizer band could be reduced.

Varvel and others (G.E. Varvel, H.L. Meredith, and R.K. Severson, 1986, Agron. J. 78:775-779) compared acid-urea-phosphate with diammonium phosphate on highly calcareous soils of the Red River Valley area of Minnesota and North Dakota. Fertilizers were placed with the seed and plant stand determined. Plant populations were not significantly affected by fertilizer treatment (Table 11).

Reports on the effects of acid-based materials on emergence, other than the study noted above, were not found in the literature. The effects of acid-based fertilizers, however, would not be much different than that of conventional fertilizers. On calcareous soils, the pH of the fertilizer band with acid-based materials is similar to that with conventional fertilizers and, therefore, ammonia toxicity would be similar for both types of fertilizer. On neutral and acidic soils, the use of acid-based materials has reduced ammonia volatilization due to the somewhat lower pH values and, therefore, it is possible that ammonia toxicity to seeds and seedlings may be less with acidified urea than with urea.

(5) Plant Availability of Nitrogen

Plant growth studies are required to assess fully the efficacy of acid-based nitrogen fertilizers. Bole (J.B. Bole, 1986, Can. J. Soil Sci. 66:189-193) evaluated the plant availability of nitrogen from acid urea phosphate and urea-MAP fertilizers using ^{15}N as a tracer and soft white wheat as a test crop (Table 12). Efficiency of the acid-urea-phosphate was similar to that of conventional urea-MAP when values for placements were averaged. The uptake of fertilizer nitrogen was greater when the urea-MAP was banded than when it was mixed with the soil. In contrast, uptake of nitrogen from the acid urea phosphate was greater when mixed than when banded.

Gasser and Penny (J.K.R. Gasser and A. Penny, 1967, J. Agric. Sci. 69:139-146) at Rothamsted, England noted that solutions of urea nitrate (urea plus nitric acid) "scorched" permanent grass and urea-nitrate produced less dry matter containing less nitrogen than did ammonium nitrate (Table 13). Studies were also conducted with acid-urea-nitrate, acid-urea-phosphate, and ammonium nitrate with barley as a test crop. Rates of nitrogen added were 0, 37, 75 and 112 kg N/ha. On average (average of three rates) acid-urea-phosphate increased grain yield more than ammonium nitrate at the Woburn site, a sandy loam soil with pH = 5.5 (Table 14). Yield on the Rothamsted soil (CL, pH = 6.2) was similar for all fertilizers.

Varvel and others (G.E. Varvel, H.L. Meredith and R.K. Severson, 1986, Agron. J. 78:775-779) compared acid urea phosphate and diammonium phosphate for spring wheat. Source of nitrogen had no effect on yield or nitrogen content (Table 15).

The studies cited above indicate nitrogen availability from acid-based fertilizers is generally similar to that from conventional fertilizers.

(6) Availability of Soil Minor Elements in the Zone of Fertilizer Application

Westfall and Hanson (D.G. Westfall and R.L. Hanson, 1985, J. of Fert. Issues 2:42-46) measured DTPA extractable zinc and iron concentrations in fertilizer bands of acid-based and conventional fertilizers in an acidic and a calcareous soil. The application of acid-urea-phosphate generally produced the highest levels of DTPA extractable Zn and Fe in the slightly acid soil (Tables 16 and 17). Zinc and iron, however, are seldom deficient in acidic soils and, therefore, the agronomic advantage of this increased solubility is questionable. In contrast, the application of acid-urea-phosphate to the calcareouus soil decreased DTPA extractable Fe as compared to ammonium polyphosphate (APP) and APP + ammonium hydroxide. There was no consistent difference in zinc levels among the fertilizer treatments applied to the calcareous soils.

Mortvedt and Kelsoe (J.J. Mortvedt and J.J.Kelsoe, 1987, J. of Fert. Issues 4:29-35) examined minor element availability to corn forage from conventional 10-34-0 and two acid type fertilizers at two soil pH levels. Concentration of Fe, Mn and Zn in plants was similar for the various fertilizer types at both soil pH levels (Table 18).

The results of these studies indicate that acid-based fertilizers have no agronomic advantage over that of conventional fertilizer with respect to soil minor element availability.

Summary and Conclusions

Application of acid-based fertilizers (e.g., urea and phosphoric and/or sulfuric acid) resulted in lower pH's in the fertilizer band than did conventional fertilizers on slightly acidic soils immediately after application. The pH of fertilizer bands with acid-based fertilizers was similar to conventional fertilizers on calcareous soils. The pH of fertilizer bands on all soils was similar for acid-based and conventional fertilizers a few days after fertilizer application; i.e., even in instances in which the pH is much reduced in the fertilizer band with acid-based fertilizers, the effect is very temporary.

Solubility of phosphorus in fertilizer bands with acid-based fertilizers immediately after application was equal to or greater than with conventional fertilizers. However, about 10 days after application solubility of phosphorus in acid-based fertilizer bands is usually less than for conventional fertilizers of similar composition and much less than that in convetional (e.g., urea + MAP) N-P dual bands. These results imply that acid-based fertilizers (e.g., acid urea-phosphate) would supply less phosphorus to plants during the entire growth period than would conventional fertilizers banded into the soil.

Plant uptake of phosphorus from acid-based phosphorus fertilizers was generally similar to that from conventional phosphorus fertilizers. It should be noted, however, that the acid-based fertilizers usually did not perform quite as well as the conventional fertilizers when the fertilizers were banded into the soil.

Volatilization of ammonia from acid-based fertilizers is much less than from fertilizers such as conventional urea when these fertilizers are applied to soils and not worked into the soil, but only on neutral and acidic soils. Volatilization of ammonia from acid-based fertilizers was similar to that from conventional fertilizers when these fertilizers were applied to calcareous soils. It should be noted that losses of nitrogen fertilizers via volatilization can be virtually completely eliminated by banding the fertilizer into the soil.

Plant availability of nitrogen from acid-based fertilizers was on average about equal to that from conventional fertilizers.

Application of acid-based fertilizers to acidic soils increased solubility of soil Fe and Zn in the fertilizer band to a greater extent than conventional fertilizers. In contrast, acid-based fertilizers solubilized less Fe than conventional fertilizers in a calcareous soil. Zn concentrations in the fertilizer bands in calcareous soils were similar for both acid-based and conventional fertilizers. Concentrations of minor elements in plants and total uptake were similar for acid-based and conventional fertilizers.

In summary, acid-based fertilizers offer no agronomic advantage over conventional fertilizers. Plant availability of phosphorus from acid-based fertilizers may be slightly less than from conventional fertilizers. Farmers considering the use of acid-based fertilizers should first consider the cost per unit weight of plant nutrients among the various fertilizers. All costs, including purchase price, handling, and equipment used in handling the fertilizer, should be considered.

Table 1. Soil pH in 0.01 M $CaCl_2$ extracts of the fertilizer injection zone as influenced by fertilizer treatment and time.

	Days after Application				
	1	10	25	50	75
Treatment	Ascalon (Non-Calcareous)				
No fertilizer	6.2	6.4	6.2	6.3	6.1
APP alone	6.3	6.3	6.0	5.8	5.8
NH_4OH + APP	7.3	7.2	6.9	6.5	6.4
AUP alone	3.6	6.2	6.1	5.9	5.8
	Weld (Calcareous)				
No fertilizer	7.6	7.7	7.6	7.8	7.9
APP alone	7.5	7.6	7.5	7.6	7.7
NH_4OH + APP	7.9	7.7	7.7	7.7	7.8
AUP alone	7.6	7.8	7.7	7.8	7.9

Table 2. $NaHCO_3$ - Ext. P in fertilizer injection zones as influenced by fertilizer treatment and time (ppm).

	Days after Application				
	1	10	25	50	75
Treatment	Ascalon (Non-Calcareous)				
No fertilizer	9	10	10	9	8
APP alone	128	92	84	60	68
NH_4OH + APP	186	99	80	72	76
AUP alone	180	100	83	52	58
	Weld (Calcareous)				
No fertilizer	11	12	12	12	13
APP alone	119	85	92	76	67
NH_4OH + APP	175	130	103	110	77
AUP alone	258	128	63	53	43

Table 3. Soil pH in the Fertilizer Placement Zone as affected by Nitrogen Fertilizer and Soil Type.

	pH (in Water)		
Treatment	Stockton (LS)	Stockton FSL	Almasippi LS
None	5.2	7.2	8.5
Urea + MAP	8.5	8.2	8.9
AS + MAP	5.6	6.1	8.1
AN + MAP	6.0	6.8	8.4
AH + MAP	6.6	6.9	8.6
AU + MAP	8.3	8.3	8.9
MAP alone	5.8	6.0	7.8

AS - ammonium sulfate
AN - ammonium nitrate
AH - ammonium hydroxide
AU - acidified urea

Table 4. Water Soluble Phosphorus in the Fertilizer Placement Zone as Affected by Nitrogen Fertilizer and Soil Type (mg).

Treatment	Stockton (LS)	Stockton FSL	Almasippi LS
None	2.2	2.2	1.1
Urea + MAP	32	30	8.5
AS + MAP	20	26	3.6
AN + MAP	18	17	3.7
AH + MAP	31	21	8.5
AU + MAP	29	23	6.7
MAP alone	21	19	5.7

Table 5. Yield of Dry Matter with Acid Urea Phosphate and MAP-Urea (g/pot)

	Acid Urea Phosphate			MAP - Urea	
Soil	Unfert.	Band	Mix	Band	Mix
Acid	4.4	10.6	8.7	12.4	10.2
Neutral	2.3	11.0	12.7	11.8	11.9
Calcareous	6.9	16.1	15.1	12.9	15.1
Mean	4.6	12.5	12.3	12.4	12.4
		\12.4/		\12.4/	

Table 6. Percent Utilization of Phosphorus from Acid Urea Phosphate and MAP-Urea.

	Acid Urea Phosphate		MAP - Urea	
Soil	Band	Mix	Band	Mix
Acid	21.0	13.5	31.3	12.5
Neutral	36.1	31.7	49.0	19.3
Calcareous	19.4	22.8	23.1	24.9
Mean	25.5	22.7	34.5	18.9

Table 7. Yield and Phosphorus Content of Wheat with DAP and Urea Phosphate (Average of 3 Expts).

Treatment	Rate (Kg P/ha)	Yield (Kg/ha)	P Content (%)
No fertilizer	0	2800	0.24
UP	25	3300	0.24
	50	3200	0.23
DAP	25	3100	0.26
	50	3100	0.25

Table 8. Fertilizer P Uptake, and Yield of Canola as Affected by Various N-P Dual Bands.

Treatment	Days before ^{32}P Uptake	P Uptake at Flowering (%)	Yield (g/pot)
No P	-	-	11
P with Seed	8	44	47
Urea + MAP	26	50	27
AS + MAP	19	52	28
Urea + H_3PO_4	25	44	26
Urea + MAP (Inc.)	20	50	38

Table 9. Loss of N as Ammonia from Surface Applications of Urea and Urea-Phosphate.

Soil	Treatment	Loss (%)
Thurman (pH = 6.8)	Urea	61.1
	Urea-P	0.1
Ida (pH = 7.8)	Urea	5.1
	Urea-P	1.1
Nicollet (pH = 7.0)	Urea	4.6
	Urea-P	0.2
Hayden (pH = 7.7)	Urea	22.2
	Urea-P	0.8
Webster (pH = 7.3)	Urea	12.8
	Urea-P	1.1
Average:	Urea	21.2
	Urea-P	0.7

Table 10. Ammonia Volatilization from Surface Application of Urea and Urea Phosphate to a Calcareous Soil.

Treatment	Rate (Kg N/ha)	Loss (%)	
Urea	25	21.9	\
Urea	50	21.7	21.5
Urea	100	20.9	/
Urea-P	25	17.7	\
Urea-P	50	22.7	21.5
Urea-P	100	24.0	/

Table 11. Effect of Seed-Placed Fertilizer on Plant Populations. (Average of 3 Expts.)

Treatment	Rate (Kg N/ha)	Plant Pop. (Plants/m^2)
O	-	238
Urea-P	22	248
	44	236
DAP	22	244
	44	235

Table 12. Uptake of N from Urea and Acid Urea Phosphate (% Utilization).

	Acid Urea Phosphate		Urea-MAP	
Soil	Band	Mix	Band	Mix
Acid	41.9	32.9	45.9	32.7
Neutral	47.2	59.9	58.5	52.8
Calcareous	47.1	61.2	45.3	56.4
Mean	45.4	51.2	49.9	47.3
	\ 48.3 /		\ 48.6 /	

Table 13. Yield and N Uptake by Permanent Grass with Urea Nitrate and Ammonium Nitrate.

Treatment	Rate (Kg N/ha)	Yield* (Kg/ha)	N Uptake (Kg/ha)
O	-	4131	101
A.N.	112	6709	184
	224	8075	250
Urea-Nitrate	112	6417	156
	224	6664	191

* Yield of 2 cuts.

Table 14. Yield of Barley Grain with Ammonium Nitrate, Urea Nitrate and Urea Phosphate.

	Yield (Kg/ha)	
Treatment	Rothamsted	Woburn
O	2951	1590
A.N.	3875	3136
Urea-Nitrate	3808	3405
Urea-P	3909	3730

Table 15. Effect of Seed Placed N and P on Yield and N Concentration in Spring Wheat (Average of 3 Expts.).

Treatment	Rate (Kg/ha) N	Rate (Kg/ha) P	Yield (kg/ha)	N Content (%)
O	0	0	2800	1.47
U.P.	22	25	3300	1.54
	44	50	3200	1.46
DAP	22	25	3100	1.54
	44	50	3100	1.50

Table 16. The DTPA Extractable Zn in Fertilizer Injection Zones of Ascalon and Weld Soils as Influenced by Fertilizer Treatment and Time.

Treatment	Days after Application 1	10	25	50	75
	Zn (ppm)				
	Ascalon (Acid)				
No Fertilizer	1.4	1.6	1.1	1.2	1.1
APP alone	1.6	1.9	1.2	1.2	1.2
NH_4OH + APP	1.9	2.1	1.2	1.6	1.4
AUP alone	2.0	1.9	2.8	2.7	2.4
	Weld (Calcareous)				
No Fertilizer	0.5	0.9	0.5	0.4	0.4
APP alone	0.5	0.8	0.6	0.5	0.4
NH_4OH + APP	0.6	0.7	0.5	0.5	0.4
AUP alone	0.4	0.7	0.7	0.5	0.5

Table 17. The DTPA Extractable Fe in Fertilizer Injection Zones of Ascalon and Weld Soils as Influenced by Fertilizer Treatment and Time.

Treatment	Days after Application				
	1	10	25	50	75
	Fe (ppm)				
			Ascalon (Acid)		
No Fertilizer	11	17	12	12	11
APP alone	22	15	18	20	19
NH_4OH + APP	18	23	12	14	12
AUP alone	58	18	22	26	28
			Weld (Calcareous)		
No Fertilizer	3.0	3.5	4.3	2.7	2.1
APP alone	10	8.0	4.9	5.8	5.0
NH_4OH + APP	6.6	5.6	4.6	3.8	3.1
AUP alone	4.2	3.8	4.4	3.7	2.5

Table 18. Minor Element Status of Corn Forage with Conventional and Acid-Based Fertilizers.

Treatment	Soil pH = 5.8		
	Nutrient Concentration (ppm)		
	Fe	Mn	Zn
0	61 (0.36)**	139 (0.82)	36 (0.21)
10-34-0	43 (0.77)	106 (1.91)	21 (0.37)
10-30-0 *	47 (0.84)	106 (1.89)	21 (0.38)
10-30-0-7 *	45 (0.70)	122 (1.88)	25 (0.38)
	Soil pH = 7.6		
0	56 (0.26)	52 (0.24)	22 (0.10)
10-34-0	45 (0.35)	64 (0.49)	17 (0.13)
10-30-0 *	46 (0.39)	69 (0.59)	15 (0.13)
10-30-0-7 *	44 (0.43)	67 (0.65)	14 (0.14)

* Acid-based fertilizer (urea and phosphoric acid with and without sulfuric acid).

** Uptake of nutrient in Mg/pot.